Volume 106
Number 1
Spring 2020

Journal of the WASHINGTON ACADEMY OF SCIENCES

ISSN 0043-0439

Issued Quarterly at Washington DC

Washington Academy of Sciences
Founded in 1898

Journal of the Washington Academy of Sciences (ISSN 0043-0439)

Published by the Washington Academy of Sciences

email: wasjournal@washacadsci.org
website: www.washacadsci.org

The Journal of the Washington Academy of Sciences

The *Journal* is the official organ of the Academy. It publishes articles on science policy, the history of science, critical reviews, original science research, proceedings of scholarly meetings of its Affiliated Societies, and other items of interest to its members. It is published quarterly. The last issue of the year contains a directory of the current membership of the Academy.

Subscription Rates

Members, fellows, and life members in good standing receive the Journal free of charge. Subscriptions are available on a calendar year basis, payable in advance. Payment must be made in US currency at the following rates.

US and Canada	$30.00
Other Countries	$35.00
Single Copies (when available)	$15.00

Claims for Missing Issues

Claims must be received within 65 days of mailing. Claims will not be allowed if non-delivery was the result of failure to notify the Academy of a change of address.

Notification of Change of Address

Address changes should be sent promptly to the Academy Office. Notification should contain both old and new addresses and zip codes.

Postmaster:

Send address changes to WAS, Rm GL117, 1200 New York Ave. NW
Washington, DC 20005

Academy Office

Washington Academy of Sciences
Room GL117
1200 New York Ave. NW
Washington, DC 20005
Phone: (202) 326-8975

Volume 106
Number 1
Winter 2020

Journal of the

WASHINGTON

ACADEMY OF SCIENCES

ISSN 0043-0439 **Issued Quarterly at Washington DC**

EDITOR'S COMMENTS

Presenting the 2020 Spring issue of the *Journal of the Washington Academy of Sciences*.

We start with the continued tale of Libby Haynes, the story of aviation weather forecasting from one of our members.

A strategy for STEM inspiration going beyond the classroom is the next paper. We very much need people in STEM fields to solve the problems we do have and those to come.

The third paper looks at the specific STEM field of engineering and considers trends in federal funding and representation of women.

The next paper is about Mars. Ancient river morphological features on Mars address our curiosity about water and the history of water on Mars.

The final paper is mathematical treatise on elementary divisors.

There is no science bite for this issue. Please consider submitting short (typically one page) papers on an interesting tidbit in science. There are a lot of interesting tidbits out there. Every science field has them. They sit in your brain ready to share. We all want to learn about things in fields other than our own. So pile them up and send them in.

The Journal is the official organ of the Academy. Please consider sending in technical papers, review studies, announcements, SciBites, and book reviews. Send manuscripts to wasjournal@washacadsci.org. If you are interested in being a reviewer for the *Journal*, please send your name, email address, and specialty to the same address. Each manuscript is peer reviewed, and there are no page charges. As you can tell from this issue we cover a wide range of the sciences.

I encourage people to write letters to the editor. Please send by email (wasjournal@washacadsci.org) comments on papers, suggestions for articles, and ideas for what you would like to see in the Journal. I also encourage student papers and will help the student learn about writing a scientific paper.

Sethanne Howard

Journal of the Washington Academy of Sciences

Board of Discipline Editors

The *Journal of the Washington Academy of Sciences* has a twelve member Board of Discipline Editors representing many scientific and technical fields. The members of the Board of Discipline Editors are affiliated with a variety of scientific institutions in the Washington area and beyond — government agencies such as the National Institute of Standards and Technology (NIST); universities such as Georgetown; and professional associations such as the Institute of Electrical and Electronics Engineers (IEEE).

Washington Academy of Sciences
1200 New York Avenue
Rm G119
Washington, DC 20005

Please fill in the blanks and send your application to the address above. We will contact you as soon as your application has been reviewed by the Membership Committee. Thank you for your interest in the Washington Academy of Sciences.

(Dr. Mrs. Mr. Ms)_

____

Business Address

____

Home Address

____

Email

____

Phone ____

Cell Phone ____

preferred mailing address

____Business ____Home

Type of membership

____Regular ____Student

Schools of Higher Education attended	Degrees	Dates

Present Occupation or Professional Position ______________________
Please list memberships in scientific societies – include office held

____

____

____

Instructions to Authors

1. Deadlines for quarterly submissions are:

   Spring – February 1 | Fall – August 1
   Summer – May 1 | Winter – November 1

2. Draft Manuscripts using a word processing program (such as MSWord), not PDF. We do not accept PDF manuscripts.
3. Papers should be 6,000 words or fewer. If there are seven or more graphics, reduce the number of words by 500 for each graphic.
4. Include an abstract of 150-200 words.
5. Use Times New Roman, font size 12.
6. Include two to three sentence bios of the authors.
7. Graphics must be easily resizable by the editors to fit the Journal's page size. Reference the graphic in the text.
8. A full page in the Journal is 6.5 x 9″. This includes the margins and headers and footers.
9. Use endnotes or footnotes. The bibliography may be in a style considered standard for the discipline or professional field represented by the paper.
10. Submit papers as email attachments to the editor or to wasjournal@washacadsci.org .
11. Include the author's name, affiliation, and contact information – including postal address. Membership in an Academy-affiliated society may also be noted. It is not required.
12. Manuscripts are peer reviewed and become the property of the Washington Academy of Sciences.
13. There are no page charges.

Washington Academy of Sciences Affiliated Institutions

National Institute for Standards & Technology (NIST)
Meadowlark Botanical Gardens
The John W. Kluge Center of the Library of Congress
Potomac Overlook Regional Park
Koshland Science Museum
American Registry of Pathology
Living Oceans Foundation
National Rural Electric Cooperative Association (NRECA)

Memories by Libby
Bail Out Libby!

Elizabeth Haynes
Air Weather Service USAF

Mrs. Elizabeth Haynes wanted some possible memories of a future airline captain she had known in the distant past, September of 1953 being the last time she saw him. Her request appeared on the REPA (Retired Eastern Pilots Association) Website Notices page in autumn 2016, with her email address. Sadly no one responded to her over the next 5-6 months so she got in touch again and this time gave the REPA historian some further information and a story or two about Eddie (as she called him).

Seems a long time ago Eddie was flying aerobatics in a PT-23 with Libby, a young woman friend of his, and suddenly yelled at her, ***Bail out!***

<u>Libby picks up the story</u>:

I was unaware of any problem, but knew it just wasn't in his nature to do this as a joke, so I didn't answer, but obeyed as quickly as I could. I had been sitting on a parachute because I had flown my first solo cross-country the day before, July 4, 1952, and had checked it out from Andrews AFB (the FAA required the parachute on one's first solo cross-country). So over the side I went! Eddie dove in to our home field and landed while I came down in a pasture, and the farmer there took me back to the airport. Eddie's comment to me was, Boy, am I glad to see you! I was pretty much OK, just a sprained back and fractured ankle bone.

Later we learned there was a crack in the carburetor gasket that leaked only when flying inverted. After rolling out, the leak caught fire; Ed expected the left wing to blow off. It didn't, because that wing tank was full to the cap; no fumes. When he rolled to a stop, he was not on fire, but all the fabric on the fuselage had burned off. The plywood floor of my front cockpit was burned through. Ed was somewhat protected by the tank of oil between the cockpits; he was painfully burned, but not deeply enough to

leave scars. Yes, this memory is still very vivid. Our guardian angels were both on duty that day! (I am convinced that there are squadrons of guardian angels assigned to watch over pilots) . . . Figure 1 shows Libby in her plane.

Figure 1: This is my "Firebird," at Hybla Valley Airport south of Alexandria, Virginia, summer 1953. I am the pilot in the front seat and my younger brother, Ed Daggit (future army paratrooper) is in the rear, taxiing for takeoff.

I wish someone had thought to take a photo of the airplane in its burned-out condition when Eddie landed it. Everyone at that little airport pitched in to repair it. I can't imagine what their labor would have been worth. I bought the muslin for the fuselage and sewed it to shape on my mother's sewing machine, and bought the nine gallons of dope we used, five gallons of aluminum and four of bright red. And I must've paid the professionals who overhauled the engine and found the broken gasket, but I don't remember doing it.

After being a widow for 25 years I finally got into my husband's keepsake drawer and found his primary training log book. It was entirely by one instructor, in the same 65 hp. Aeronca L3. On his first lesson's entry,

the instructor wrote "shows aptitude." Solo flight after 8 hr. 5 min, "well done." and the last entry, after 35 hr. 10 min, "O.K. for flight test." All in 54 days total. He was 19 years old.

My husband, William Haynes, was commissioned from aviation cadets in March 1942; his class was activated as the 64th Troop Carrier Group and delivered C-47s to North Africa with a belly full of fuel for the crossing (Natal to Dakar). The crew made coffee in flight in a butt can propped in a helmet shell with sand and avgas burning in it. Gives me the shudders to think of it! Yes, they were very young!

He retired from the Air Force in 1964, with about 8500 hours, mostly in C-47s, C-54s, and C-124s. He never lost an airplane or a passenger or crew member, and nobody was seriously wounded, but a few times during the Italian campaign they came back with bullet holes and a feathered prop.

I was an Air Force officer too—OCS at Lackland AFB, Class 51-C (see Figure 2). My first assignment as a shiny new second lieutenant was to Kelly AFB, in the weather station as an observer. Working in base ops, I could see the departures and arrivals board, and begged rides in Air Force airplanes. Rules were easier in those days! Once I had a ride in a T-33, and the pilot let me take the stick for a few minutes. That is a cherished memory. From Kelly to Wichita took a bit under an hour. It took four hours to get back in a C-47.

Back to Eddie, did he ever tell you why he had to join the Marines right out of high school? And that he was honorably discharged as disabled, in a wheelchair, and told he would never walk again? He told me that if he couldn't fly, he didn't want to live, so he made himself get up and walk and drove a taxi to pay for his flight instruction, to earn his licenses and ratings. Flying for an airline was his dream career, and it's good to know that he did it.

I don't know whether he told anybody else this story below, or whether he was ashamed of it.

Figure 2: Libby at OCS, Class 51-C, Lackland AFB Texas

Ed grew up in Anacostia, DC, on the steep ridge of land paralleling the river just east of Bolling AFB. From his back yard, he could look down onto the airfield and dream about becoming a pilot. (At this time, I don't know if he had ever had a flying lesson, but he had done a great deal of reading about flying.) One fine August night, he told me, while he was still in high school, the Devil got into him (his words) and he walked down the hill, squirmed under the fence, and crept onto the air base. He climbed into a parked P-51 and sat in the cockpit reading the takeoff check list by flashlight. Then, he started the engine, taxied onto the north-south runway, and took off. He flew the plane around for about fifteen minutes, then came in and landed without incident.

When he came to a stop, he was met by the M.P.s, who took him into custody and to the DC police. He was taken to Junior Village (the juvenile detention facility), until he saw the juvenile court judge. His sentence was probation, return to high school, graduate, and then immediately join the Marine Corps. If he served one hitch and was honorably discharged, the judge said, his juvenile arrest record would be expunged.

He did exactly as he was told, joined the Marines, and was sent to the Southeast Asia Theater. There he developed a severe case of "jungle rot" — a hideous infestation of tropical flesh-eating bacteria — and after a long hospitalization and honorable discharge, still in a wheelchair, and continuing treatment, he finally, due to his own determination to live to fly, was completely healed.

As I mentioned, he drove a taxi to earn money for flying lessons. After earning his commercial license, he spent several weeks as a crop duster to pay for his instrument rating. Just before flying off in his PT-23 for that job, he grinned at me and said, "They expect to lose a third of their first-season dusters!" But he came back.

I can't help but think of Ed as "a born pilot." You know the saying, "Old pilots never die; they just go on to a new plane."

I have tried and tried to figure out the thought processes of that juvenile judge. Was he amused that Eddie, while certainly doing something illegal, was skilled enough to carry it off without hurting either any person or damaging government property? Did he see the potential in this young man? (I'm sure Ed never got in trouble with the law again!) The judge certainly could have totally destroyed his future, but he did not, and his judgment was correct. I wonder if he ever knew how Eddie turned out.

Our paths parted, and the last time I saw Eddie was in September 1953. Please tell me about the rest of his life. I'm sure it was competent, professional, and honorable, and I hope joyous and complete.

Editor's Note: It certainly was!!!

If you knew Eastern Captain Edmond M. (Eddie) Kerge (he retired as an L-1011 Captain based at JFK and died December 7, 1999) and would be willing to share some of your memories of him with Libby, she would greatly appreciate it…

Figure 3 is the memorial to Eastern pilots. Figure 4 shows the L-1011. Figure 5 shows the memorial plaque listing Kerge's name.

Figure 3: Eastern pilots' memorial

Figure 4: Lockheed L-1011

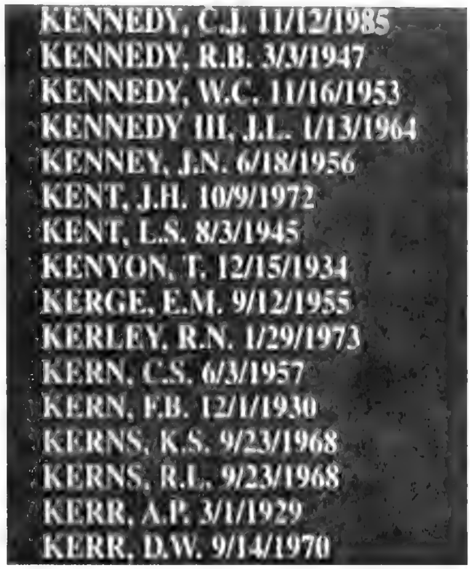
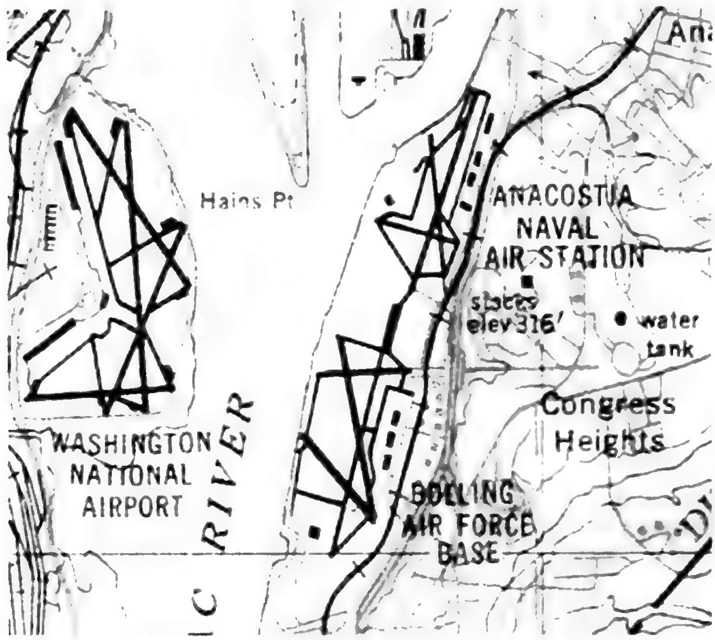


Figure 5: Bronze plaque commemorating all 6,962 living and deceased pilots who flew for Eastern Airlines, with their dates of employment.

Figure 6 shows Bolling Field in 1945. The pictures are from the web site: **Abandoned & Little-Known Airfields** by Paul Freeman, 2017.

A 10/23/43 aerial view looking southwest at Bolling Field from the 1945 AAF Airfield Directory (courtesy of Scott Murdock) depicted the field as having 4 paved runways.

Figure 6: Bolling Field in 1945

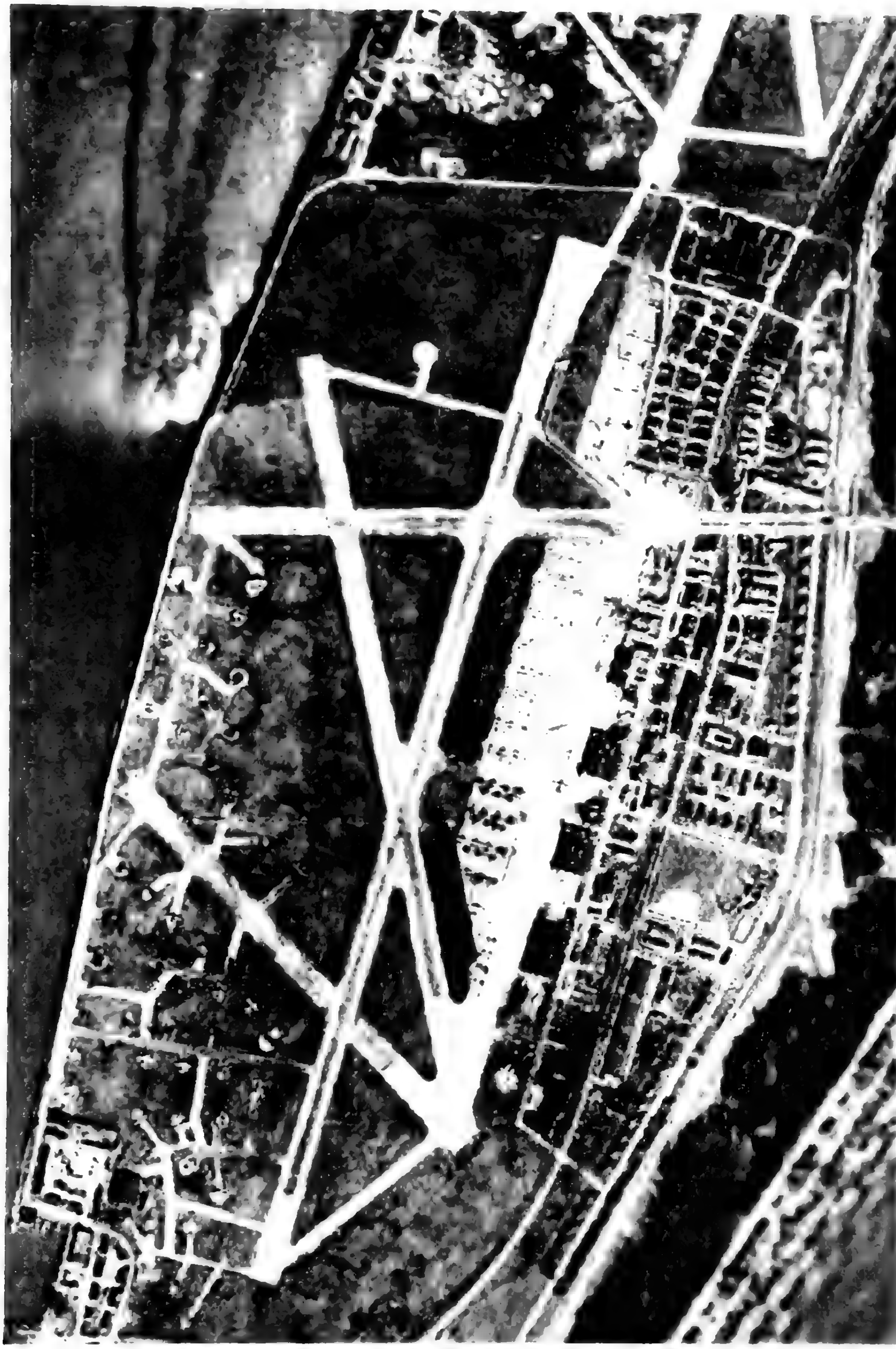


Anacostia NAS & Bolling AFB, as depicted on the 1949 USAF Target Complex Chart.

Figure 7 – National airport is at the left margin

The north-south runway is the longest runway, parallel to the Potomac River. National airport is at the left margin across the river. Due to this proximity, Bolling Air Force Base and the adjoining Anacostia Naval Air Station to the north were closed to fixed-wing aircraft operations in 1962, and all military aircraft were relocated eight miles to the east to Andrews AFB, which is spacious enough to accommodate them.

In Figure 8 the photo looks down on Bolling AFB, north is to the top of the picture, as in Figure 7. Edmond Kerge lived on the street under the trees in the lower right of the picture. That wooded area is on a very steep drop to the eastern edge of the air base.



A 1949 aerial view of Bolling AFB,

showing an amazing number of aircraft parked on the field,

including large numbers of single-engine & multi-engine aircraft on the ramp on the east side.

Figure 9

Beyond the Classroom: A Strategy for STEM Inspiration

Paul Arveson

Washington Academy of Sciences

Abstract

Many studies have reviewed the shortcomings in STEM education in the US and have offered ways to improve it. Most of the studies have addressed traditional K-12 and undergraduate classroom methods. This article reviews the literature and identifies an emerging trend in "beyond the classroom" methods, which have the potential for inspiring more students to engage in STEM activities that can lead to valuable careers for the individual and society.

The Need for STEM Skills and Knowledge

PROGRESS IN SCIENCE, TECHNOLOGY, engineering and mathematics (STEM) fields provides the best opportunity for raising the quality of life of our society. Therefore, scientific academies have sought to "advance science, serve society" – the motto of the American Association for the Advancement of Science (AAAS). But surveys show that the demand for STEM graduates far exceeds the supply. Only about five percent of all employees are in STEM careers, including all the medical workers [1]. What can educators, parents and volunteers do to increase the supply?

Consider a random sample of K-12 students. The following paths to a STEM career might occur:

- Path 1 - Students are already inspired to pursue science early in life.
- Path 2 - Students get interested in STEM at some time in their school years.
- Path 3 - Students change to a STEM career at some time after they graduate.

Path 1 students are already motivated, and education can only encourage that path. For Path 3 students, some experience later in life causes a shift in career interests as adults; educators have little influence over those experiences. But for Path 2 students, inspiring educational experiences have the possibility of recruiting students toward a STEM career. As educators and STEM volunteers, we have the opportunity of creating those inspiring experiences.

We know from reports and our own experience that many children get "turned off" to science and math at some point in the middle grades. What causes these reactions to STEM subjects? Some of the most valuable insights came from the work of Sheila Tobias, one of the pioneers in the women's equality movement of the 1970s. She was an insightful advocate of improved math education, especially for girls and women. Tobias reinterpreted "math inability" as "math anxiety" [2]. In a traditional classroom setting, the task of solving a math problem in front of the class can be painful and trigger more fear and anxiety. This anxiety leads to avoidance of the subject. Since math is a system that builds in a logical sequence, any gaps in knowledge lead to further difficulties later on. This causes increased anxiety and avoidance, leading to a lifelong block and a feeling that "I'm just not good at math." By examining their feelings, not just the math problem, Tobias uncovered psychological barriers in math achievement caused by a restricted educational process. Tobias noted that math anxiety was particularly challenging for female students in this era.

Tobias later addressed a related question: "What makes science 'hard'?" In order to explore this question she created controlled experiments in which faculty in non-science fields were asked to attend a science lecture or take a science course. Her findings indicated that science ability was not a matter of intelligence, but of how different individuals process their perceptions of the world. Her conclusions were summed up in the book "They're not dumb; they're different" [3]. Tobias' books were bestsellers and helped to shake up the STEM education establishment. She is currently exploring the way engineering is taught, and she advocates that all students should be exposed to this subject, because of its importance in our technological world. [4].

STEM Education Gaps

The recognition of educational barriers and gaps became widely realized after the launch of Sputnik in 1957, a shock which provoked the United States government to focus attention on STEM education [5]. New federal initiatives were established to develop improved methods, equipment and textbooks. Ample new funding was provided by the National Science Foundation, and high-level studies were conducted among science educators, including the Physical Science Study Committee (PSSC) [6] and the Biological Sciences Curriculum Study (BSCS) [7].

These initiatives have since been followed by a continuing series of studies, curricula, and textbooks designed to improve science education and assess its results. Here we can only highlight a few of the more recent studies.

The Obama administration, via the Office on Science and Technology Policy, in 2010 launched the President's Council of Advisors on Science and Technology (PCAST).

Senior experts were invited to author a series of influential studies [8]. PCAST 2010 dealt with K-12 STEM education [9]. Under the heading "Troubling Signs", the Executive Report had this to say:

> "Despite our historical record of achievement, the United States now lags behind other nations in STEM education at the elementary and secondary levels. International comparisons of our students' performance in science and mathematics consistently place the United States in the middle of the pack or lower. On the National Assessment of Educational Progress, less than one-third of U.S. eighth graders show proficiency in mathematics and science.
>
> Moreover, there is a large interest and achievement gap among some groups in STEM, and African Americans, Hispanics, Native Americans, and women are seriously underrepresented in many STEM fields. This limits their participation in many well-paid, high-growth professions and deprives the Nation of the full benefit of their talents and perspectives.
>
> It is important to note that the problem is not just a lack of proficiency among American students; there is also a lack of interest in STEM fields among many students. Recent evidence suggests that many of the most proficient students, including minority students and women, have been gravitating away from science and engineering toward other professions. Even as the United States focuses on low-performing students, we must devote considerable attention and resources to all of our most high-achieving students from across all groups.
>
> Schools often lack teachers who know how to teach science and mathematics effectively -and who know and love their subject well enough to inspire their students. Teachers lack adequate support, including appropriate professional development as well as interesting and intriguing curricula. School systems lack tools for

assessing progress and rewarding success. The Nation lacks clear, shared standards for science and math that would help all actors in the system set and achieve goals. As a result, too many American students conclude early in their education that STEM subjects are boring, too difficult, or unwelcoming, leaving them ill-prepared to meet the challenges that will face their generation, their country, and the world."

Focus on Standard Assessments

In the recent decade, education studies have shifted toward a more business-oriented focus on measuring and evaluating results against national standards, the assumption being that over time, schools with learn what works and will migrate toward those practices. Initially a "Common Core" of standards were defined for STEM fields, but due to political opposition, today only standards for math and English remain. Currently the Common Core state standards initiative for mathematics has been defined and adopted by all but nine states. It is not a curriculum but a set of standardized goals in a sequence. The standards are evidence-based. They "draw on conclusions from the Trends in International Mathematics and Science Study (TIMSS) and other studies of high-performing countries.... the progression in the Common Core State Standards is mathematically coherent and leads to college and career readiness at an internationally competitive level." [10] However, the Common Core does not include science, technology or engineering standards.

Recently there has been increasing push-back on the business-like orientation on measurement of performance, from both teachers and students. The pressure to achieve numerical test scores has been questioned as the main goal. Moreover, it has proven difficult to devise performance metrics that are fair to all teachers.

A recent study has shown that behavior (*e.g.* number of absences and suspensions, grade point average, and on-time progression to 10th grade) of 9th graders is a stronger predictor than test scores of student success [11].

Education is not like a commercial business, where performance is easy to measure in terms of dollars. It should not be surprising that there would be ongoing challenges in educational assessment. Moreover,

assessments alone do not guide educators into learning what works. There is still a strong need for experimentation and innovation.

Behavior-focused education emphasizes engaging students in "fun" and hands-on activities are part of a well-balanced exposure to science. And moving some of these activities outside the classroom setting may be especially influential for some of the "Path 2" students.

Technology Education Lags

Another PCAST report from 2013 [12] noted that

> "... our world today relies to an astonishing degree on systems, tools, and services that belong to a vast and still growing domain known as Networking and Information Technology (NIT). NIT underpins our national prosperity, health, and security. In recent decades, NIT has boosted U.S. labor productivity more than any other set of forces. .... In order to sustain and improve our quality of life, it is crucial that the United States continue to innovate more rapidly and more creatively than other countries in important areas of NIT. Only by continuing to invest in core NIT science and technology will we continue to reap such enormous societal benefits in the decades to come."

The client-side tools of information technology are converging: the desktop, laptop, smart phone, and the Internet. Practically everybody will need to use these technologies at home and work. They are getting smarter, smaller, and faster. Some human-based skills (visual pattern recognition, natural language understanding, delicate manual tasks) are difficult for machines to replicate, but the recent emergence of powerful machine learning tools and the advent of "big data" are rapidly overcoming many of these difficulties.

The tasks assumed for robots so far are often unimaginative and childish, such as contests, ball throwing, cleaning floors, etc. These are easy but not very valuable or marketable tasks. They may be giving the wrong image of robotics' potential to both students and business people. Students working in robotics will increasingly aim toward the development of truly practical, money-saving or risky tasks. These will often lend themselves to inventions that can be developed and marketed. This prospect will continue to inspire some young people.

Traditional Education Can't Keep Up

These new and emerging technologies are evolving too fast for traditional educators to develop the knowledge, skills and materials needed to adequately inspire and engage young people in the classroom. The situation calls for a greatly increased engagement of professional scientists and engineers who are already using these skills and technologies. Hence, we believe that this kind of educational activity should extend beyond the classroom.

A 2012 National Academies study on discipline-based classroom learning [13] focused on research on undergraduate STEM teaching methods. Not the methods themselves, but the research on those methods. The conclusion was that we don't have much evidence on what works, and whatever we do know was not included in this report. Many educators have now realized that traditional classroom methods, no matter how well they are conducted, cannot keep up with the speed of change in STEM subject matter. A 2015 report by the National Research Council [14] concluded:

> "The ways in which young people learn about science, technology, engineering, and mathematics (STEM) has fundamentally changed in the past decade. More so than ever, young people now have opportunities to learn STEM in a wide variety of settings, including clubs, summer programs, museums, parks, and online activities. They spend more time in supervised programs outside of school, and they have greater access to on-demand learning resources and opportunities. At the same time, STEM learning outside of school has become a focal piece of the education opportunities provided by many national nonprofit organizations, statewide education networks, federal programs, and corporate and family foundations. And there is growing evidence that opportunities to learn STEM outside of school directly affect what is possible inside classrooms, just as what happens in classrooms affects out-of-school learning."

In 2016 the NAS published a study [15] that surveyed several examples of innovative practices in collaborative STEM education that could be widely adopted. This publication is pertinent to our concern. Here is an excerpt from the Summary:

> "Educators, policy makers, industry leaders, and others recognize the importance of strong college-university-industry collaboration in

preparing the STEM workforce of the future. Two recent reports from the President's Council of Advisors on Science and Technology (Engage to Excel, 2012 [16]) and the National Science and Technology Council (Federal STEM Education 5 Year Strategic Plan, 2013 [17]) emphasize the importance of encouraging stronger university-industry partnerships as vehicles to enhance student learning and diversify pathways to careers in STEM. The landmark National Academies report, "Rising Above the Gathering Storm" (National Research Council, 2007 [18]), also examined the essential relationships between university-industry collaboration and regional economic growth. The report suggested that partnerships among academia, governments, and industry succeed when all members of the partnership see the collaboration as in their best interests, and further, pursue these relationships in the spirit of mutual trust and appreciation of the value that each partner brings to the table."

Three overarching findings emerged from the 2016 NAS study:

• "Significant numbers of university students are graduating with STEM degrees, but many lack the right combination of technical and employability skills needed to thrive in the workplace. In short, we have many students with credentials, but fewer with the requisite skills to succeed early in STEM careers. This situation is particularly acute with minority students and female students, who are still significantly underrepresented in the STEM workforce and in STEM degree fields in most 4-year universities.

• "Employers are increasingly focusing on the skills and abilities new hires possess, rather than the specific field in which an individual has obtained a degree or credential. While there is a need for STEM graduates who will work as professional research and development scientists and engineers (so-called STEM narrow skills), there is a growing need for individuals who apply STEM knowledge and skills in technologically sophisticated occupations that require a facility with STEM concepts, but not necessarily a bachelor's degree (so-called STEM broad skills). There is also a growing need for students with a breadth of skills outside of their core STEM discipline, including skills that are perhaps best developed through a well-rounded liberal education that includes STEM courses, humanities courses, and experiences in the arts. These include problem solving, critical thinking, teamwork and collaboration, communication, and creativity.

• "A robust and effective STEM workforce development ecosystem requires proactive steps on behalf of university leaders, local employers, and intermediary organizations to build and sustain alliances that benefit students and regional economic development. Most of the concrete and high-impact strategies that surfaced during the course of the study—including those recommended in this report—do not require extensive policy change by governing boards, but rather can be undertaken at the classroom, department, or program level within a college or university, often in collaboration with a local employer. ...."

Diversity and Inclusion

A new 2019 report from the AAAS, "Levers for Change: An assessment of progress on changing STEM instruction" [19] emphasized the need for expanding outreach and access to the entire population, combined with innovative experiential methods. The report made frequent use of the term "research-based instructional strategies" (RBIS) to designate the set of active teaching and learning practices that support improved student learning. In general, such active, collaborative, and student-engaging strategies support learning, independent of discipline (Kuh, 2008 [20]; Pascarella & Terenzini, 2005 [21]; see also Fairweather, 2008 [15]). (A list of 32 such strategies is given in [22]).

The following excerpts are findings drawn from the 2019 report:

> "Women, minorities and persons with disabilities remain underrepresented in STEM professions while they are an increasing percentage of the overall U.S. workforce. Alternative and diverse approaches to excellence in education and mentoring " - NSF Strategic Plan [23].

> "To meet the demands of a global economy and foster technological innovation, the United States needs more well prepared and diverse workers in science, technology, engineering and mathematics (STEM) fields (PCAST, 2012) [16]. National studies reveal racial and ethnic disparities in science literacy, as well as in educational achievement, employment, and health outcomes that depend on STEM education [24]. All Americans should have equitable opportunities to enter the high-paying, high-status, and high-employment jobs typical of STEM careers, and to learn, enjoy, and use science to make informed decisions in everyday life, in the

voting booth, and in their communities Access to STEM learning opportunities begins in childhood and requires well-prepared preK-12 and informal educators to teach and inspire young people in mathematics and science (PCAST, 2010). High-quality STEM education for all undergraduates is essential to achieving all of these national goals. A large and ever-growing body of education research demonstrates that pedagogical approaches that foster active and collaborative learning can enhance student learning, attitudes, and persistence in STEM educational paths."

"Yet most students do not experience these engaging pedagogies. Indeed, students from underrepresented racial and ethnic groups, as well as low-income and first-generation college students, are more likely to benefit, yet least likely to experience them .... Policymakers view improving instruction as a "best bet" [23] and as the "lowest-cost, fastest policy option to providing the STEM professionals that the nation needs" [16]."

Fairweather [15] reviewed the literature on promising practices in STEM undergraduate instruction and concluded that the problem was not a lack of knowledge about which teaching practices were effective, but rather insufficient use of these practices: The key to improving STEM undergraduate education lies in getting the majority of STEM faculty members to use more effective pedagogical techniques than is now the norm in these disciplines. (p. 13)"

"...[M]ore effort needs to be expended on strategies to promote the adoption and implementation of STEM reforms rather than on assessing the outcomes of these reforms."

"...The problem in STEM education lies less in not knowing what works and more in getting people to use proven techniques (p. 28)."

"Thus, it is crucial that we learn how to lower these barriers and promote adoption of effective evidence-based teaching practices...."

"There is sufficient evidence from education research in and across the disciplines to indicate that active learning experiences are good for students and support their learning, attitudes, sense of belonging, and persistence in STEM. (We know that ongoing studies will further detail these benefits and how they vary among different student groups and settings.)" (p. 9).

Mentoring is also prescribed as a strategy for improving the retention rates in STEM education for Latina women, as shown in a recent paper by Staveley [28]. She recommended nine suggestions for effective mentoring of Latina women.

The AAAS "Levers of Change" report studied undergraduate college instruction in classrooms. But the evidence indicates that successful inspiration of students in STEM hinges on their experience in early K-12 grades, in experiences both inside and outside the classroom. Therefore, we believe that some of the most important "Levers of Change" will be located in these experiences. Hence, to get a more complete picture of the scope of RBIS education, it will be necessary to widen the scope of the research to cover these activities, many of which are occurring "under the radar" of formal educational systems and assessments.

STEM Support in the Classroom

One way to fill the STEM gap is to bring scientists into the classroom. A local ongoing STEM program that has been doing this is the AAAS Senior Scientists and Engineers (SSE) STEM Volunteer Program that is managed by Betty Calinger at AAAS headquarters for schools in the DC, suburban Maryland and Virginia (DMV) area [29]. The volunteers, led by Dr. Don Rea, recruit other professional scientists (either working or retired) to attend a local school regularly once or twice a week to guide and support the teacher in that classroom.

After-School Activities

A transitional move from the classroom is through after-school activities or out-of-school time ("OST"). These are of course traditional activities, especially for sports, but also for school clubs, science fairs, school plays, projects etc. There is a growing interest in such activities among many community stakeholders (including home schoolers and an emerging movement called "community schools"). In this way teachers can receive up-to-date and refresher training for in STEM in after-school settings [30]. But teachers alone cannot be expected to perform all the STEM education responsibilities.

Science fairs and STEM fairs

Science fair and STEM fair competitions are very popular and widespread. Competitive fairs are supported and standardized by a number of national organizations, including the Regeneron Science Talent Search, the National Science Bowl, Broadcom Masters (for middle school students), the International Science and Engineering Fair (for high school students), FIRST Robotics [31], the Biology Olympiad, the Physics Olympiad, the Google Science Fair, and many more. In our area federal employees support and mentor students in many of these science fair projects. A summary of local science fairs and programs has been compiled on the website of the Washington Academy of Sciences [32].

The science fair is a venerable tradition across the US. But the quality of student projects in these activities is uneven, and their concept of the "scientific method" has a narrow definition that has been carried along as part of the tradition. Also, they give students a very limited exposure to the range of STEM research in modern practice. At one science fair I recently attended, I noted that ***not one*** of the projects required the students to go outdoors (*e.g.* "Which detergent cleans the best?"; "Mold growth in bread".). Science fairs could provide an opportunity for inner-city students to engage with nature – there are many local parks, rivers, and the Chesapeake Bay where field trips could be done. The Smithsonian's Nature Center, the National Arboretum, the National Zoo, and the Botanical Garden are all located in the city.

Many fields of science – such as astronomy, archaeology, botany, ecology, geology, meteorology, oceanography, paleontology, and zoology – require careful exploration of the natural environment. Unfortunately, many school science fairs do not take advantage of opportunities for helping children to encounter the natural world in a scientific way. The lack of exposure to nature outdoors may give urban students a limited view of the real world, as well as of their opportunities in scientific careers.

Despite these limitations, the fact that science fairs are deeply embedded in the culture and curricula of most public schools means that they should continue to be encouraged and promoted. We only need to help teachers to improve and leverage this tradition.

STEM activities beyond the classroom

The conclusion of the Levers of Change report and earlier studies is that there is likely to be increased student engagement, inspiration, and commitment to STEM education outside the traditional classroom environment, in less formal, unstructured activities that feel more like "fun" to the student.

Some of these STEM-related non-formal activities include:

- Activities in "maker spaces", in which children of diverse ages engage in hands-on design and construction of various devices.

- Robotics clubs, such as FIRST Robotics [31], which have recruited a nationwide team of robot design engineers and a hierarchy of competitions.

- Special-interest clubs for high school age children, including Explorers Clubs, Boy and Girl Scouts, Red Cross first aid units, mathematics and chess clubs, etc.

Many of these activities are largely student-run, so by definition they are engaging to students. They develop confidence and leadership skills as well as technical skills. And most of them lead directly in career-relevant directions.

STEM Activities of the Washington Academy of Sciences

The preceding sections of this article have reviewed the general findings of educators and policy makers regarding STEM education. These scholars have arrived at several consistent recommendations regarding improvements that should be made in STEM educational activities, both inside and outside the classroom. At this point we wish to describe closely one specific case as an example of what is being done – the STEM activities in which the Washington Academy of Sciences has been directly involved.

The Washington Academy of Sciences assumes its jurisdiction to cover the District of Columbia and surrounding suburbs in Maryland and Virginia within a radius of 50 miles. Most members live in this region, and this is the region covered by our awards program, board members and volunteers [32].

The Academy benefits from the abundant scientific facilities and professionals in this area. In addition to some leading universities, we have

several institutions that treat specialized branches of science. This region includes the National Institutes of Health (NIH) – the presence of which partly accounts for the growing number of other medical research companies in our area. There are major government scientific headquarters, including the National Institute of Standards and Technology (NIST). There is the Office of Science of the Department of Energy, and we have the National Ocean and Atmospheric Administration (NOAA). There is the National Aviation and Space Administration (NASA). The Applied Physics Lab of Johns Hopkins University is an individual lab. On the military side there are three major naval facilities: Naval Research Lab, the US Naval Observatory, and the Naval Surface Warfare Center (at Carderock). There is the Army Research Laboratory, Walter Reed Army Institute of Research, and Fort Detrick, which is in Frederick. There is also the nation's cryptographic installations around Fort Meade and the National Security Agency (NSA). And many more.

Programs that use experienced scientists and engineers inside the school setting can supplement the educational work of teachers and the standard academic curriculum. But as the reviews of STEM education above show, in recent years there has been increasing recognition that for many reasons, classroom methods are limited in their ability to engage students and attract them to consider the many STEM career opportunities in government and industry. For example, a 2016 report identified the high priority areas of technology that are needed by NASA [33]. Two of NASA's High Priority Technology Areas are:

- TA 4, Robotics and Autonomous Systems
- TA 11, Modeling, Simulation, Information Technology, and Processing

These fields are specifically relevant to the activities of young people in maker spaces and robotics programs. Research and development in these areas is ongoing at the local NASA Goddard Spaceflight Center, Johns Hopkins Applied Physics Laboratory, and elsewhere in the Academy's region. The activities described below are limited to certain areas of Maryland and DC. However, there are also a number of similar programs and activities in northern Virginia.

Figure 1. Dr. Paul Hazan judges a project at a science fair (photo by the author)

The Washington Junior Academy of Sciences has managed a program since the 1940's to provide science fair judges to various schools hosting K-12 STEM fair conferences and events in the DMV region. In the 1990s, Dr. Paul Hazan (see Figure 1) served as the judges' coordinator and offered leadership to grow the number of judges and events in which we participated. David Moran in Maryland and Jim Egenreider in Virginia helped to expand the recruiting of judges, including the participation of other members of the Academy's Board of Managers. Dick Davies assumed leadership of the Junior Academy in the early 2000's and continued to broaden the reach of our STEM programs. He recruited Kevin Brogan as a partner in organizing teams of judges. In recent years Dr. Vijay Kowtha and the author have led judging at the Blair Magnet High School and other STEM events (see Figure 2).

Figure 2. Winners of the Blair Magnet HS STEM Fair, 2020 (photo by V. Kowtha)

Maker Spaces

"Maker spaces" are large rooms dedicated to the creation and construction of devices such as robots by children of all ages. These constructions require special tools and products. Many new types of technical devices are being widely adopted in industry, and school systems struggle to keep up with an awareness of these devices and the skills needed to control them. These devices include small low-cost computers (*e.g.* Raspberry Pi) and microprocessors (*e.g.* Arduino) that are integrated into and shaping many industries, such as robotics, drones, and the Internet of Things (IoT). Other tools that are finding increased applications are 3D printers, laser cutters and CNC routers. The engineering skills to effectively learn and use these devices include CAD (computer-aided design), coding, cybersecurity, soldering and wiring, electronic sensors, network communications, etc. These are the kinds of skills taught in maker spaces and robotics clubs, such as the ones established by FIRST Robotics, Inc.

Dr. Kowtha has served for many years as a creator and coordinator of robotics and maker space clubs in College Park, Greenbelt, Landover, Maryland, and in DC, with an emphasis on outreach to underrepresented students in STEM. In 2017 he established a branch of FIRST Robotics (Team Illusion 4464) in Greenbelt, MD. Using the acronym MASER-DC (Mentors Advancing STEM Education and Research in DC) [34], he has

organized maker spaces for K-12 students in DC and Prince Georges County, Maryland.

Figure 3. Beltway Plaza Mall maker space, 2017. (photo by the author)

For several months, the maker space for Team Illusion 4464 was housed in a storefront in Beltway Plaza Mall (see Figure 3). This enabled passersby to see the activities ongoing and many new students were recruited in this way.

Figure 4. Dr. Kowtha in the new maker space for *Bladerunners*. (photo by the author)

Recently Dr. Kowtha established an all-girls robotics club called *Bladerunners* that operates out of a space he rented in College Park, Prince Georges County, MD (see Figure 4).

Rockville Science Center, Maryland

The Rockville Science Center [35] is a volunteer outreach organization to inspire an interest and knowledge of science in the local community. Under the leadership of Robert Eckman, the Rockville Science Center hosts a variety of maker groups, including MoCo Makers, which presently meets in a room in Rockville Library. Access to this space is limited to library hours, and the space is limited (see Figure 5).

Figure 5. MoCo Makers participating in a project (photo by the author)

In the library space MoCo Makers leader Matt Zamora offers weekly presentations to the public on a wide range of technologies. In the past three years, the following technologies have been explored and discussed among the participants: Field-programmable gate arrays, cluster computing, Raspberry Pi, Verilog syntax, modular electronics, MakerBot for telescopes, glove sensors, 3D printers, prototyping, stepper motors, servo motors, drones, MIDI streams, solar sensors, git, digital radio, MicroPython, Kickstarter, GPS, Chromecast, fractals, microcontrollers, Slack, Fusion 360 for CNC manufacturing, cryptocurrency, blockchain, Arduino, neural networks, diodes, algorithms, encryption, navigation, sun tracking, self-propelling spheres, compiling C++, LEDs, operating systems, mobile apps,

reverse engineering, electrical power grids, robot analysis, torque, oscilloscopes, resistors, touchscreen LCD, Beaglebone, car transmissions, temperature sensors, robotic mounts, and the Vagrant software development tool see Figure 6).

Figure 6. Rockville Science Center storefront, opened in 2020 (photo by R. Eckman)

Recently Rockville Science Center has acquired a store-front STEM program maker space in the center of the city. This large space, which gets ample public traffic, will provide high visibility for many planned science and engineering activities every day, including scientist panel discussions, a planetarium and a biology workshop. Also, it will allow student access to the space at times when the library is closed.

Rockville Science Center also hosts a monthly Science Cafe, a Young Adult Science Cafe, several robotics programs, and tours of local science and engineering labs. They provide summer camps and hosts an annual Rockville Science Day in April (but not this year!)

Other beyond-the-classroom programs similar to these are being conducted in DC and Virginia. As the "baby boomer" generation is now reaching retirement, we can expect to have an increasing reservoir of experienced people from whom to recruit and engage in STEM educational efforts, and as Academy members increase their engagement in tutoring, judging, and mentoring, we can expect to report more success stories in the future.

These programs are successful at attracting students because they leverage the time that is available for after-school activities, and likewise they leverage the time that is available to retired senior scientists and engineers. The programs bring these two groups together for STEM activities that are fun, challenging, and career inspiring. Moreover, the hands-on activities in building robots, programming computers, operating and constructing drones and other machines provides students with ample opportunities for creativity and experiences not available in the classroom.

Although these activities are called "beyond the classroom", by no means does this imply that schools are not involved. Partnering with local schools and school systems is essential. Partnering has mutual benefits including:

- Schools provide the pool of students who may be recruited for beyond-school programs
- Interactions with teachers are necessary to avoid duplication and fill specific gaps in instruction
- Teachers help identify students who are academically prepared to benefit from beyond-school programs

Local science and engineering businesses and government agencies are also stakeholders in beyond-the-classroom programs. They often recognize these programs as a potential source of talent for employment, and in some cases, they support these programs for that reason (see Figure 7).

Figure 7. Typical activity in the Beltway Plaza Mall maker space with a diverse group of students and mentors.
(photo by the author).

Summary

The reports cited above indicate that education researchers are increasingly recognizing the potential of beyond-the-classroom programs to increase the quality, quantity and diversity of STEM students. The Washington Academy of Sciences has a unique position and opportunity to greatly enhance the effectiveness of STEM education in the DC area. There are already several beyond-the-classroom programs that are open for business, but they need more volunteer mentors, more equipment, and more financial support.

Recommendations

The current pandemic experience is reminiscent of the Sputnik experience in the US: it has shocked us into recognizing a new existential threat to survival. One of the logical outcomes of this experience will be the demand for an increased number of STEM graduates, as scientific research is the only strategy we have to mitigate such threats in the future. This will require further removal of psychological barriers to STEM education as well as the creation of many new kinds of opportunities for young people to engage in STEM activities.

All of the US states have an Academy of Science (or Sciences), and they are affiliated with the National Association of Academies of Science. the Association's stated policy is "... to ensure that their students shall conduct original research and technological or engineering design projects that contribute to a fuller understanding and enrichment of the world rather than simply repeating previous research or template experiments." [36]

This policy emphasizes the value of originality and creativity in STEM activities. Academies of science have a unique vantage point for assessing the quality of STEM education activities, and for direct participation in making improvements in ways that are appropriate for their particular location and environment.

The case study above reviewed the current STEM education activities of one local region of the US. Similar activities are replicated all over the country; science fairs, in particular, are a venerable and widespread activity, but they tend to be unoriginal and uninspiring. There is an expanding interest in hands-on activities centered around maker spaces and the creation of microprocessor-based devices and 3D printers. These items have now become affordable to many students. Currently, with stay-at-home orders in place, many students are able to continue their construction activities at home. Some are fabricating 3D-printed face shields and other PPE for use in medical and other settings. The NIH has encouraged this practice and has even created a website where individuals can post new designs for 3D printing – even including 3D models of the SARS-CoV-2 spike protein molecule [37]. Undoubtedly our current home-based education experience will lead to more useful ideas and products.

Here are some examples of ways in which the academies can support STEM education:

1. As the saying goes, "a crisis is a terrible thing to waste". The management and resolution of the current pandemic must be guided by scientific knowledge, some of which does not yet exist. Governments at local levels are now recognizing their increasing dependence on specialized technical guidance, equipment and institutions. Constituents in a local jurisdiction are likely to be willing to increase their investments in STEM education to meet future crises. The local academy of science could play an important role in advocating for these investments.

2. Establish partnerships with nonprofit organizations (such as FIRST Robotics) that operate maker spaces with high outreach potential. Provide publicity and financial support to these organizations and recruit mentors to serve as participants for their programs.

3. Create a Committee for Encouragement of Science Talent. This committee will be responsible for developing procedures for monitoring and evaluating the effectiveness of activities to encourage young people outside the classroom setting. The committee can provide recommendations for awards and recognition to individuals, such as an award for Leadership in STEM Inspiration to be include among the awards offered by the academy.

4. Partner with other local scientific societies (such as Sigma Xi and IEEE) in volunteer activities and sponsorships.

5. Offer a formal call for papers from high school and undergraduate students. Submissions will be peer-reviewed and qualified papers will be published in the academy's journal, or in Sigma Xi's Chronicle of the New Researcher, which already has in place a peer-review and editorial process.

6. Replicate the work of the AAAS STEM Volunteer Program, which recruits volunteer professional scientists to serve in public school science classrooms in the DC area [29].

7. Ask WAS members to donate supplies, such as surplus scientific equipment and furniture, to help equip the maker spaces.

8. Recruit STEM fair judges for school events by reaching out to local scientific institutions and companies.

9. Create a network to recruit senior STEM Fair awardees to serve as tutors and mentors for younger students.

10. Establish partnerships in STEM projects between students in different countries, using Internet collaboration tools. This will allow students to experience the increasingly international character of professional research activities.

These are just a few examples of strategies and activities of an academy that can be developed into detailed plans to fit the particular needs and resources in a particular state or metropolitan region.

References

1. Ecklund, E.H. and Scheitle, C. (2014). "Religious Communities, Science, Scientists and Perceptions: A Comprehensive Survey", presentation at AAAS Annual Meeting, Feb. 16, 2014.
2. Tobias, S. "Overcoming Math Anxiety", Norton & Co., New York (1978).
3. Tobias, S. "They're not dumb; they're different", Research Corp., Tucson (1990). https://rescorp.org/gdresources/publications/Tobias-Sheila_Theyre-Not-Dumb.pdf
4. Tobias, S. "What makes science and math 'hard'?", https://www.youtube.com/watch?v=QXGQuQuKOio
5. Gibson, E. (2020). "NSF and Postwar US Science", *Physics Today*, 73(5), p. 40-46.
6. Physical Science Study Committee (PSSC), https://en.wikipedia.org/wiki/Physical_Science_Study_Committee
7. Biological Sciences Curriculum Study, https://en.wikipedia.org/wiki/Biological_Sciences_Curriculum_Study
8. President's Council of Advisors on Science and Technology (PCAST), https://obamawhitehouse.archives.gov/administration/eop/ostp/pcast/docsreports
9. "Prepare and Inspire: K-12 Science, Technology, Engineering, and Math (STEM) Education for America's Future", PCAST (2010), https://obamawhitehouse.archives.gov/sites/default/files/microsites/ostp/pcast-stem-ed-final.pdf
10. "Common Core State Standards Initiatives: Myths vs. Facts", http://www.corestandards.org/about-the-standards/myths-vs-facts/

11. C. K. Jackson, "The Full Measure of a Teacher", https://www.educationnext.org/full-measure-of-a-teacher-using-value-added-assess-effects-student-behavior/
12. "Designing a Digital Future: Federally Funded Research and Development in Networking and Information Technology", https://obamawhitehouse.archives.gov/sites/default/files/microsites/ostp/pcast-nitrd2013.pdf
13. "Discipline-Based Education Research: Understanding and Improving Learning in Undergraduate Science and Engineering", https://www.nap.edu/catalog/13362/discipline-based-education-research-understanding-and-improving-learning-in-undergraduate
14. "Identifying and Supporting Productive STEM Programs in Out-of-School Settings", https://www.nap.edu/catalog/21740/identifying-and-supporting-productive-stem-programs-in-out-of-school-settings
15. "Promising practices for Strengthening the Regional STEM Workforce Ecosystem" (2016), https://www.nap.edu/catalog/21894/promising-practices-for-strengthening-the-regional-stem-workforce-development-ecosystem
16. Engage to Excel: Producing One Million Additional College Graduates with Degrees in Science, Technology, Engineering, and Mathematics, PCAST (2012), https://obamawhitehouse.archives.gov/sites/default/files/microsites/ostp/pcast-engage-to-excel-final_2-25-12.pdf
17. Federal STEM Education 5 Year Strategic Plan (2013), https://obamawhitehouse.archives.gov/sites/default/files/microsites/ostp/stem_stratplan_2013.pdf
18. “Rising Above the Gathering Storm”, National Research Council (2007), https://www.nap.edu/read/11463/chapter/2
19. “Levers for Change: An assessment of progress on changing STEM instruction” (2019), https://www.aaas.org/sites/default/files/2019-07/levers-for-change-WEB100_2019.pdf
20. Kuh, G. D. (2008). High-impact educational practices: What they are, who has access to them, and why they matter. Washington, DC: AAC&U.
21. Pascarella, E., & Terenzini, P. (2005). How college affects students: A third decade of research. San Francisco: Jossey-Bass.
22. "32 Research-Based Instructional Strategies" (2020), https://teachthought.com/pedagogy/32-research-based-instructional-strategies/

23. Investing in America's Future: NSF Strategic Plan, FY 2006-2011, NSF 06-48, https://www.nsf.gov/pubs/2006/nsf0648/NSF-06-48.pdf
24. Allum, N., Besley, J., Gomez, L., & Brunton-Smith, I. (2018). Disparities in science literacy. Science 360(6391), 861-862.
25. Rutherford, F. J., & Ahlgren, A. (1989). "Science for all Americans: Education for a changing future". New York, NY: Oxford University Press.
26. Snow, C. E., & Dibner, K. A. (Eds.) (2016). "Science literacy: Concepts, contexts, and consequences". Washington, DC: The National Academies Press. https://doi.org/10.17226/23595
27. Singer, S. R. (2013). Advancing research on undergraduate science learning. *Journal of Research in Science Teaching*, 50(6), 768-772
28. Staveley, J. (2019). "The Effective Strategies to Increase Latina Women in STEMM Fields through Mentoring." *J. Wash. Acad. Sci.* 105(4), 2019.
29. AAAS Senior Scientists and Engineers STEM Volunteer Program, https://www.aaas.org/programs/STEM-volunteers
30. "Preparing for Success in STEM", Click2Science Professional Development Framework, http://click2sciencepd.org/framework
31. FIRST Robotics, https://frc-events.firstinspires.org/
32. STEM fair competitions and programs in the DC metropolitan area, https://www.washacadsci.org/programs/
33. NASA High-priority Technology Areas, https://www.nap.edu/read/23582/chapter/4
34. MASER-DC, https://www.maserdc.org
35. Rockville Science Center, https://www.rockvillesciencecenter.org/
36. STEM Education Policy Resolution, National Association of Academies of Science (NAAS), https://kb.osu.edu/bitstream/handle/1811/53716/OJS111N2-5_58.pdf
37. NIH 3DE Print Exchange, https://3dprint.nih.gov/discover

Bio:

Paul Arveson currently serves as VP of the Junior Academy on the Board of the Washington Academy of Sciences. His first career was as a physicist in the Navy, where he conducted research in acoustics and oceanography. He has a BS in Physics and an MS in Computer Systems Management and has served as a developer and technology architect for various agencies. He is co-founder of the Balanced Scorecard Institute, a strategic consulting firm. Recently he served as a Senior Associate in the Dialogue on Science, Ethics and Religion Program at the American Association for the Advancement of Science.

Changing Trends in Federal Funding U.S. Doctoral Degree Programs and Women's Representation among Engineering Doctorate Recipients

Lisa M. Frehill

Energetics Technology Center, Indian Head, MD

Abstract

Federal funds played an important role in the expansion of engineering graduate programs between 1977 and 2015. Simultaneously, U.S. immigration policies enabled international students to enter for studies, while Title IX opened the doors of engineering schools to women. This article blends institutional data from the National Science Foundation's survey of federally financed research and development with Department of Education data on doctoral degrees to explore the role of women and temporary residents in this expansion of engineering higher education. This paper shows that temporary resident women were an important component of women's increased presence among recent cohorts, as temporary residents of both genders became a larger part of engineering PhD recipients. The analyses also show that mid-tier institutions appeared to provide the best point of entrée for non-citizen engineering students.

Introduction and Background

THE TWENTIETH CENTURY signaled a shift in U.S. investment in higher education, transforming the post-secondary system from an elite luxury to an accessible goal for more of the U.S. population. This expanded access, and consequently larger high-skilled human capital pool, thus enabled the rapid pace of technological advancement for the United States (Goldin and Katz 1999). Indeed, the U.S. education system has been characterized by on-going evolution, change, and expansion, offering new opportunities to new populations in new fields over its history. In this way, the complex relationship between federal educational funding, expanded access, and available human capital becomes the key driver in innovation, invention, and employment opportunity which serve as the hallmarks of the U.S. economy (Kelly et al. 1998; Optimal Solutions Group 2011).

When considering the role of technological superiority in supporting a robust economy, fields such as engineering are particularly important. A number of efforts in the last half of the twentieth century led to expansion and growth of engineering education. In 1958 Congress passed the National Defense Education Act (NDEA) as part of the response to the Soviet Union's

Sputnik launch. This Act provided loans to college students, graduate fellowships, and funded improvements in elementary and secondary science and mathematics education (Public Law (P.L.) 85-864). Seven years later, Title III of the Higher Education Act of 1965 authorized $55 million to strengthen "developing institutions," which offered or prepared students for "engineering, mathematics, physical or biological sciences, or other technological fields..." (P.L. 89-329, Title III: 1229). Among many other programs, these examples highlight the relationship between federal funding and expanded access to science and engineering education to support U.S. economic growth and technological advancement (Kelly et al. 1998).

On the human resources side of the equation post-World War II baby boomers were coming of age in the 1960s, which further spurred the growth of colleges and universities. To encourage young men to pursue engineering and natural science fields, the Military Selective Service Act of 1967 (the "Draft Act") provided grounds for military service deferment for men "whose civilian activity is found to be necessary to the maintenance of the national health, safety, or interest" which included educational pursuits "deemed essential to the national interest ..." Thus, young men could defer military service and avoid deployment by pursuing science and engineering studies - an option that was especially attractive in the Vietnam War era (P.L. 69-96).

The twentieth century also saw expanded access to higher education. For women in engineering, Title IX of the U.S. Education Amendments of 1972 was critical in opening the doors of previously-closed engineering schools.[1] The impact of Title IX on women's participation in engineering is unmistakable: whereas women earned less than 1% of engineering bachelor's degrees prior to 1972, by 1977 they earned 4%, with continued growth through to 2000, when women accounted for one-fifth of all engineering bachelor's recipients (Frehill et al. 2009).

Finally, global transformations and changes in U.S. immigration policy enabled the increased participation of temporary residents in U.S. engineering doctoral degree programs as an important component of growth of these programs in the latter decades of the 20th century. PhDs awarded to

[1] Under Title IX, "No person in the United States shall, on the basis of sex, be excluded from participation in [...] any education program or activity receiving Federal financial assistance." (U.S.C A§ 1681, Title IX, 34 C.F.R. 106.1)

temporary residents increased from 847 in 1977 to 5,786 in 2015. Between 1990 and 1994, and then from 2000 onwards, temporary residents accounted for more engineering PhDs awarded by U.S. universities than did U.S. citizens or permanent residents (NSF 2017).

The role of women and temporary residents in U.S. engineering human capital, and the intersection of these two demographic characteristics as an instance of multiple marginalities, has been a little-explored issue. In the past several years, there has been increased attention by groups such as the U.S. National Academies and the Association for Women in Science (AWIS), among others, to the persistent "double-bind" experienced by women of color in science, technology, engineering, and mathematics (STEM). (Williams et al 2014) Taking a term from a 1976 report, these new studies have sought to describe how multiple marginalities continue to affect the working lives of women in the STEM fields. (Malcom *et al.* 1976) However, the high-profile National Academies reports of 2007, 2010, and 2013 are completely silent on the potential impact of citizenship status on the careers of women in STEM. While Williams *et al.* (2014) include reference to birth origin and STEM field when describing individual research respondents, the implications of status as a temporary resident is not explored.

Additionally, in the past four decades a growing body of literature has focused on the production of STEM human resources and similarities and differences of career outcomes across demographic groups (*e.g.*, see Corbett and Hill 2015, Kanny, Sax and Riggers-Piehl 2014, Hill, Corbett and St. Rose 2010 and Frehill, DiFabio, and Hill 2008 for reviews). Quite often, especially since 2008, researchers often do not disaggregate "STEM," which obscures important differences between careers in these fields. Similar to other STEM fields, bachelor's (BS) and master's (MS) degreed engineers engage in different work than do PhD engineers. However, unlike some other STEM fields—most notably, the life sciences—MS and BS credentials have traditionally enabled engineers to secure relatively well-paying employment, posing recruitment challenges for U.S. doctoral degree programs different than those in the life sciences.[2] Engineering programs,

[2] At the bachelor's degree level, engineers with bachelor's degrees routinely earn some of the highest starting salaries when compared to their newly-graduated peers in fields like biology, business, and teaching. (Brandi et al 2010, Frehill 2011, and Langdon et al.

therefore, are often tightly connected with employers and attenuated to BS and MS needs.[3]

The engineering research workforce represents a distinct labor market. While the doctoral degree is a necessary credential for entry, as in other fields, the points of discontinuity between BS/MS-level education and doctoral education pose unique challenges for student recruitment to engineering doctoral programs. Well-paying jobs and family formation serve as economic disincentives for employed engineers to pursue doctoral degrees. Yet PhD students are a critical research workforce at universities, therefore, expansion of academic research-intensive engineering programs must solve this recruitment dilemma.

The role of federal funding in the engineering education enterprise is important to consider in this regard. Faculty secure research grants from external funders, particularly federal sources, while universities provide critical research infrastructure critical. Students support the bulk of the funded research work in exchange for tuition remission and stipends. The connection between research dollars and graduate education was quite notable in the 1990s, for example, when the National Institutes of Health doubled its research funding over a four-year period. During that period graduate education in life sciences expanded rapidly but once the doubling period ended, the large number of doctoral recipients who subsequently entered the PhD workforce found a severely limited labor market. (FASEB 2015; Frehill 2016)

This paper examines the convergence of the macro-level trends described here—namely the demographic changes in the composition of engineering doctoral degree programs, the proliferation and expansion of

2011) Advocates of increasing minority participation in doctoral engineering programs often cite the high salaries earned by new engineers as posing a special challenge for recruiting students to graduate school. Further, in fields like biology, physics, and chemistry the master's degree was sometimes considered a "consolation prize" for individuals who were not able to make-the-grade in research, but for engineering the master's is considered a valuable credential, enabling engineers to maintain currency in rapidly-changing technological environments. (Frehill 2003)

[3] Indeed, when providing guidance about PhD programs at Society of Women Engineers' conferences, the author was routinely informed by participants that when they asked the employer representatives in the career fair area about graduate school, such representatives suggested that a master's degree was "great" but that a PhD would mean the individual would be "over-qualified" and, therefore, unemployable.

these programs, and the policy framework that facilitated these changes. What has been the role of previously underrepresented groups—particularly women and international students--in the growth of the U.S. graduate engineering enterprise in recent decades? This paper will show that changes in federal funding of higher education have played a role in the general growth of engineering doctorate degrees.

In order to assess the role of demographic and funding trends the proliferation and expansion of engineering doctoral programs, and the policy framework that enabled change, the following research questions are posed:

- To what extent is there a relationship between demographic changes in engineering doctoral enrollment and the federal policy and funding changes supporting these programs?
- To what extent have changes in federal funding of post-secondary education supported increased access for U.S. women and international students in engineering PhD programs at U.S. colleges and universities?

Data and Methods

Data Sources

Three main data sources were used for this paper, all of which were accessed via the NSF WebCASPAR database system (NSF 2017). These included the Integrated Postsecondary Education Data System (IPEDS) "completions by race"[4] degree data. IPEDS data are compiled by the U.S. Department of Education from annual data submitted by colleges and universities, which are required to report as a condition of receiving federal financial aid. Second, we pulled annual data about federally financed higher education research and development (R&D) expenditures for engineering via WebCASPAR. Within the context of institutions with doctoral degree programs in engineering, which are highly dependent upon federal financing, these IPEDS and federal funding data are population data. Finally, via the same WebCASPAR system, we used data from the Survey of Earned Doctorates (SED). Administered annually to all recipients of research doctoral degrees from U.S. colleges and universities, the SED has a response

[4] This is a technical term used in the field.

rate in excess of 95 percent for each year since its first administration in 1957.

Variables

Consistent with the institutional approach of the paper, the selected datasets provided the opportunity to look at system-level and institutional level findings. The IPEDS and Federal R&D data were available at the institutional level; institutional level data were not available with the SED data. These latter data, therefore, provide additional descriptive information about the overall U.S. production of engineering PhDs. Federally Financed Higher Education R&D Expenditures in engineering were all adjusted to current (2016) dollars).

Gender is one of two key analytical variables, with results about individuals reported for women and men, consistently reported across the various datasets. Citizenship status was the second key categorical variable. IPEDS and SED provide disaggregation of degree data for two groups: U.S. citizens and permanent residents (hereafter denoted U.S.)[5] versus temporary residents (denoted "Temp. Resid." in graphs). Federal higher education R&D expenditures for engineering provide a measure of the university-based research infrastructure support for the field. These data were obtained using the NSF WebCASPAR database system for the period 1973-2015 at the institutional level.

Engineering is considered a "major field group" in NSF data publications. For additional demographic analyses, we disaggregated by specialty area for the four largest engineering fields: chemical engineering, civil engineering, electrical engineering, and mechanical engineering. As will be shown, these fields have different demographic profiles in terms of gender and citizenship status.

Women, especially temporary resident women, continue to represent relatively small numbers of students in engineering PhD programs, especially at the institutional level on which this paper focuses. This means that any given year could show a much different snapshot than the next year in the sequence. As such, we use three-year periods to even out these potential year-on-year biases. We selected the earliest and latest such periods

[5] For clarity, we often use the term "U.S." as a descriptor rather than the more cumbersome "U.S. citizens and permanent residents."

that were available in the data we used (i.e., 1977-1979 and 2013-2015) and three intervening periods: 1990-1992, 2000-2002, and 2010-2012[6]. These periods, therefore, provide snapshots of the 38-year timeframe covered by these data.

The number of doctoral degrees conferred in each of these five periods were used as a means of stratifying U.S. institutions conferring doctoral degrees. In this way, we control for the relative size of graduate engineering programs. Very large programs were defined as those that produced more than 133 PhDs in a year; large programs were those that awarded 67-133 PhDs per year); and all others that awarded one or more PhDs in a year.

Analyses

I use simple descriptive analyses to show trends for the four groups of interest: U.S. women; temporary resident women; U.S. men; and temporary resident men. Within the institutional-level data file, we also compute correlations between federally financed higher education R&D expenditures for engineering within each of the five periods under consideration with the overall number of doctoral degrees in engineering and the percentage of doctoral degrees conferred to women and temporary residents.

Post-hoc tests of the differences between correlations within each set across the five time-period snapshots were also performed. Using the Fisher r-to-z transformation (Lowry 2017), pairwise comparisons were performed, with results highlighted or noted at the bottom of each table. It should be noted, as well, that the IPEDS and financial data are population data, rather than the results of samples.

[6] IPEDS data for degrees were not available in 1978, 1980, 1982, 1983, 1984, 1986, and 1988. This means that with respect to degrees, the 1977-1979 period is an average of two (rather than three) values. Engineering R&D expenditure data were available for all years, so the 1977-1979 period included all three years. While the Survey of Earned Doctorates (SED) may have been a useful alternative source of data about doctoral degrees, these data have substantial missing data on one of our key variables-citizenship status-and are not publicly available for 2007 and later, rendering these data useless for our institutional level analyses. SED data were used only for our discipline-specific analyses due to limitations associated with availability of the IPEDS data.

Results

Figure 1, shows the overall federal R&D funding trend between 1973 and 2015 for institution groupings based on the 2013-2015 doctoral degree production. Average annual federally financed R&D increased for the very large and large institutions, while all other institutions (i.e., those that produced fewer than 67 PhDs per year in 2013-2015) experienced relatively modest growth in average federally financed R&D. In the most recent three-year period, there has been a slight decline for "All other" and a more pronounced decline for Very Large engineering PhD programs in average federally financed R&D expenditures. Finally, average federally financed R&D expenditures appear to be converging for the 11 Very Large and the 22 Large institutions.

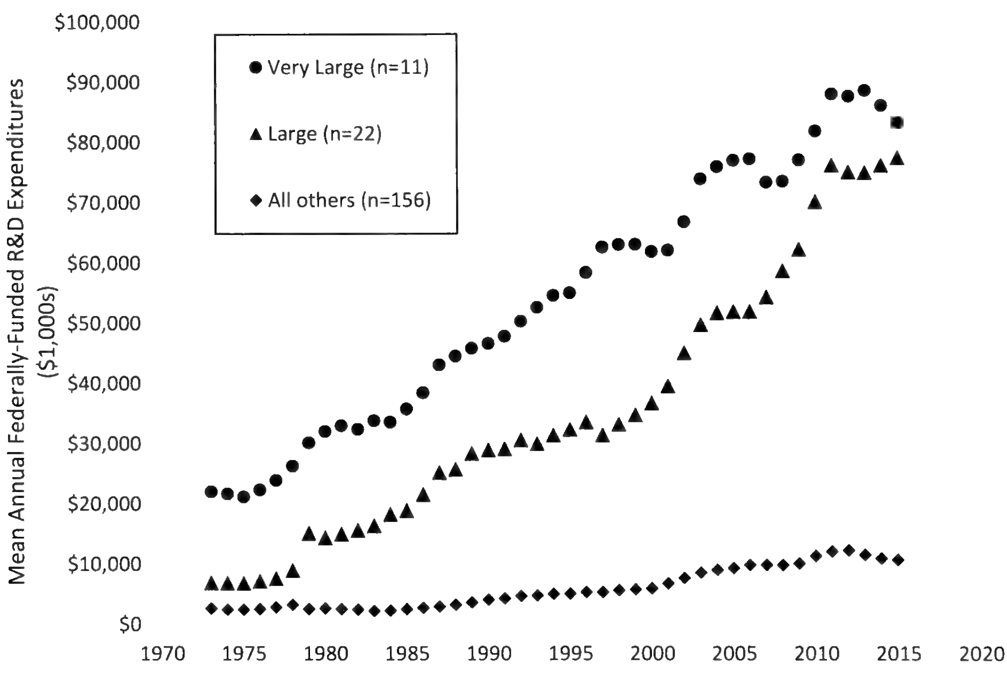


Figure 1: Annual Mean Federally Funded R&D Expenditures (in Constant 2016 $thousands) in Engineering per Institution within PhD-Cohort Size Group (Based on 2015 Doctoral Degree Conferrals in Engineering)

At the institutional level, a similar increase in temporary resident participation was evident. Figure 2 shows the number of U.S. institutions that issued at least one engineering PhD to a temporary resident student. This figure shows the same increase in temporary resident engineering PhDs over the study period, with nearly all U.S. engineering doctoral degree programs

conferring at least one PhD to a temporary resident starting in the early 1990s, as indicated by the nearly overlapping lines in Figure 2.

Figure 3 is based on all institutions that reported engineering doctoral degree awards in the study period via the IPEDS data system, disaggregated by both citizenship status and gender. Temporary resident men, especially, have been a significant – but variable-sized - population within U.S. graduate engineering populations, earning a majority of U.S. engineering doctoral awards in a brief period in the early 1990s and then again in the post-2000 period. In 2015, temporary residents accounted for 56% of all engineering doctoral degrees (temporary resident women accounted for 12%), with U.S. women accounting for an additional 11% of the doctoral degrees awarded in 2015. As shown in Figure 1, the upward trend in temporary resident women's participation in U.S. doctoral engineering programs generally parallels that of U.S. women. In the most recent period from 2010-2015, however, the increase in the number of degrees for U.S. women was 28.5% as compared to the 38.8% for temporary resident women. In contrast, the number of engineering doctoral degrees awarded to both U.S. and temporary resident men increased by about 33% in 2015 as compared to the number awarded in 2010.

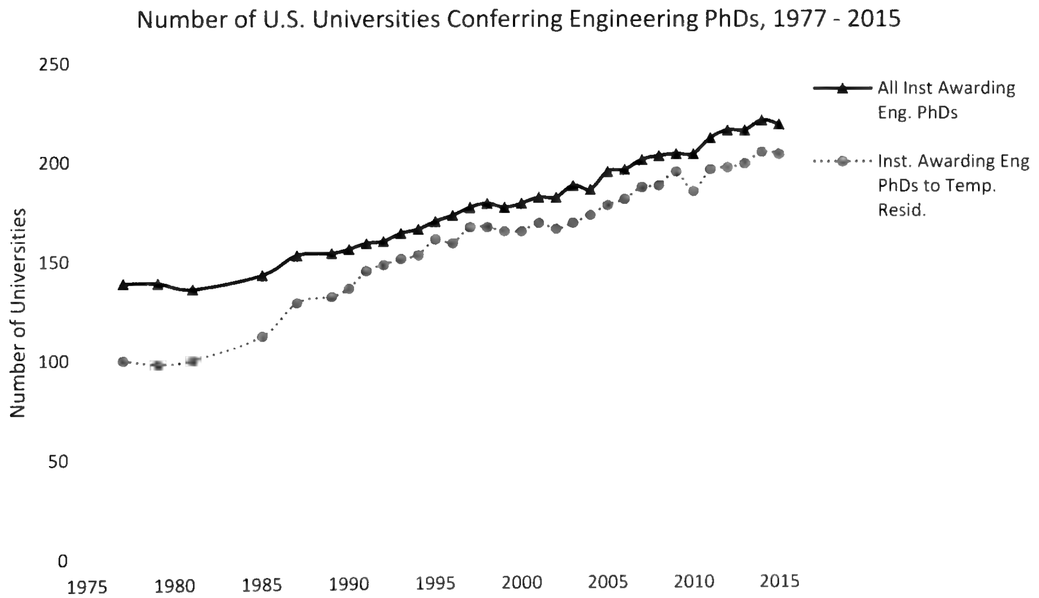


Figure 2: Trend in Engineering Doctoral Programs at U.S. Universities
Source: Author's analysis of NSF's IPEDS degree data accessed via the WebCASPAR database system.

Next we examine the descriptive statistics and correlations between demographics of engineering PhD recipients and federal R&D funding of U.S. universities. Table 1 reports the median funding level for institutions as well as degree awards by institutional group and time period. The five three-year periods were selected to show snapshots over time. As discussed, above, three-year averages are used as a standard way to account for the volatility in the small numbers of graduates when disaggregated by demographic characteristics in order to avoid the potential problem of false positive conclusions associated with change (i.e., due to year-on-year variations that are more "noise" than real effect). The first period is the earliest time at which IPEDS data for engineering disaggregated by gender and citizenship status were available, representing a time 5-7 years after Title IX. The final period represents the most recent three-year period prior to the most recent administration during which there has been a marked downturn in international graduate students at U.S. universities. (Okahana and Zhou 2019)

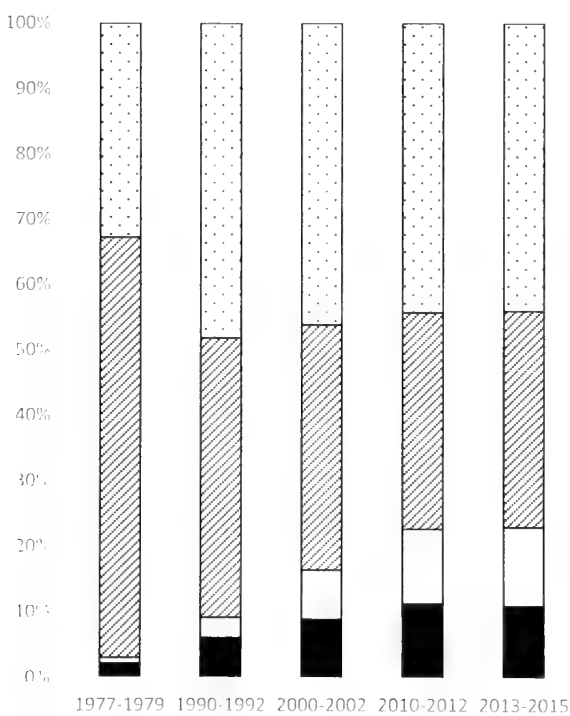


Figure3: Trend in Doctoral Degree Awards in Engineering from U.S. Colleges and Universities, 1977-2015 by Gender and Birth Origin Source: IPEDS data accessed via NSF WebCASPAR database system. Note: 1978 data were not available, therefore, the 1977-1979 period represent a two-year average, while all other periods are three-year averages

There was only one very large institution in the earliest period (1977-1979) but the number in this category (as well as the other two size categories) continued to grow through 2013-2015. The 17 very large institutions had median federal R&D expenditures in engineering of $65.5 million per year and produced about 213 PhDs each year in the most recent period, 2013-2015. In contrast, the 26 large institutions had a median $40.9 million of expenditures of federal R&D funds and graduated fewer than half as many engineering PhDs in the same period. Finally, there were 179 institutions who graduated an average of 22-23 engineering PhDs each year between 2013 and 2015, with a median of $6.9 million each year in federal-funded R&D expenditures.

Table 1. Median Funding (in millions of 2016 dollars), Average PhDs in Engineering, Percent Women and Percent Temporary Residents among Engineering PhDs, by Institutional Group and Time Period

	No. of Instit.	Median Annual Eng R&D	Annual Average PhDs	Ave. % Women	Ave. % Temp. Res.
Very Large (more than 133 PhDs/year)					
1977-1979	1	$101.6	143.5	4.2%	24.0%
1990-1992	7	$57.0	173.2	8.6%	49.1%
2000-2002	7	$86.9	169.4	16.8%	47.7%
2010-2012	12	$88.1	209.4	21.6%	55.8%
2013-2015	17	$65.5	212.7	21.8%	56.6%
Large (67-133 PhDs/year)					
1977-1979	4	$34.6	107.8	2.0%	37.1%
1990-1992	14	$25.0	89.7	8.4%	51.0%
2000-2002	16	$37.3	90.2	15.5%	56.5%
2010-2012	21	$48.2	97.0	22.6%	52.7%
2013-2015	26	$40.9	91.1	23.0%	51.1%
All Others (with 1 or more PhDs)					
1977-1979	140	$3.3	14.1	6.3%	37.1%
1990-1992	144	$3.6	19.2	10.4%	53.1%
2000-2002	166	$6.7	16.6	18.7%	55.8%
2010-2012	186	$8.1	20.6	25.1%	55.1%
2013-2015	179	$6.9	22.5	25.6%	57.2%

Table 2 examines the correlations between engineering PhD recipient demographics and federal funding levels (adjusted for inflation to constant 2016 dollars) in each of the four most recent time periods. The correlation between funding and the total number of PhDs has declined since the 1990-1992 period but remains relatively robust. There are no statistically significant correlations between the relative percentage of temporary residents and engineering R&D funding. The largest change in correlation coefficients, however, is evidenced between the percentage of women PhD recipients and engineering R&D funding; this correlation coefficient was only statistically significant in 1990-1992, with very weak or negligible associations in all other years.

Table 2: Correlations between Federal Engineering R&D Funding and PhD Recipients' Demographics and Federal Funding for Each Time Period

	Total PhDs	% Women	% Temp. Resid.
1977-1979	.809**	.035	.039
1990-1992	.501**	.177*	-.071
2000-2002	.589**	.031	-.031
2010-2012	.393**	.043	.031
2013-2015	.402**	-.005	-.038

* Indicates two-tailed significance at $p < 0.05$; ** indicates two-tailed significance at $p < 0.01$. Shading within the Total PhD column indicates the results of post-hoc tests (using the Fisher r-to-z transformation) of the differences between correlations within the column. For Total PhDs, 0.809 is larger than all others (p=0.00); 0.589 and 0.501 are equal (p=0.24) as are 0.393 and 0.402 (p=0.91); and 0.589 > both 0.402 (p=0.01) and 0.393 (p=0.01). None of the correlations in the last two columns are statistically significantly different using the Fisher r-to-z transformation. The largest difference in the % Women column produced a z=1.77 with p=0.07; while that in the % Temp. Resid. Column produced a z = 0.96 with p=0.34.

Table 3 controls for institutional type in these correlations, reporting results for the 17 institutions that were in the "very large" group in 2013-2015 (left three columns of Table 3) and the 26 institutions that were in the "large" group (right three columns of Table 3). For the very large institutions, there is a far stronger relationship between engineering R&D funding and PhD production, as evidenced by the larger correlation coefficients—all of which were statistically significant at least $p < 0.05$—in the first column of the table. However, there was a far weaker – and sometimes negative – correlation between PhD production and engineering

R&D funding for those institutions that produced between 67 and 133 PhDs per year in engineering in the 2013-2015 period. Indeed, only the 0.428 correlation in the 1977-1979 period for these 26 institutions was statistically significant.

The post-hoc tests for the correlations reported in Table 2 indicate that the correlations in the first column, those associated with the correlation between Total PhDs and federally-funded R&D expenditures, were in three groupings with the 0.809 for the 1977-1979 period significantly greater than all others; followed by the two correlations for the middle two periods; and then the two for the most recent two periods. None of the correlations in the last two columns are statistically significantly different for the five time periods shown.

Table 3. Correlations of Engineering PhD Demographics with Federal R&D Funding, by Year and Institution Classification for Top PhD Producing Institution Groups in 2013-2015

	Very Large (2013-2015) (n = 17 institutions)			Large (2013-2015) (n = 26 institutions)		
	Total Eng. PhDs	% Female	% Temp. Resid.	Total Eng. PhDs	% Female	% Temp. Resid.
1977-1979	.844**	-.213	-.251	.428*	-.122	.061
1990-1992	.870**	.414	-.129	-.044	.508**	-.176
2000-2002	**.922****	.065	-.666*	.096	.242	-.228
2010-2012	**.665***	.252	-.219	-.102	.556**	-.008
2013-2015	.761**	.184	-.326	.042	.245	-.136

* Indicates two-tailed significance at $p < 0.05$; ** indicates two-tailed significance at $p < 0.01$. Shading within columns indicate the results of post-hoc tests (using the Fisher r-to-z transformation) of the differences between correlations within the column. For Very Large institutions, Total Eng. PhDs, only 0.922 > 0.665 ($z=2.12$; $p=0.03$), no others were significant (comparing 0.922 to 0.761 had a $z=1.60$, $p=0.11$); none of the % Female or % Temp. Resid. correlations were significantly different (largest gap had $z=0.99$, $p=0.32$ in the former, and $z=1.78$, $p=0.08$ in the latter). None of the correlations within each column for the Large institutions were statistically significant when using the Fisher r-to-z transformation post-hoc test.

For both the very large and large institutions, the correlation between R&D funding and the percentage of temporary resident PhD recipients was always negative, quite volatile, and rarely statistically significant. For example, there was a strong negative correlation (-0.666) in the 2000-2002 period for the very large engineering PhD schools. The percentage of female PhDs was positively correlated with R&D funding in all but the first period for both types of schools but tended to be a stronger correlation for the large compared to the very large schools in each of the five time periods. The correlation between the percentage of women among PhD recipients and R&D funding was only significant – and of moderate size – for the 1990-1992 and 2010-2012 periods for the 26 large PhD producing engineering schools.

Next we examine the descriptive statistics and correlations between the demographics of engineering PhD recipients and federal R&D funding awarded to U.S. universities. Table 1 reports median funding level for institutions, divided by relative engineering PhD degree production. The five three-year periods were selected to show snapshots over time. As discussed, above, three-year averages are a standard way to avoid the problem of a potential false positive on change (i.e., due to year-on-year variation that are more noise than effect). The first and last periods are defined by data availability, while the other three periods were meant to provide milestone marks between the late 1970s and the present. Also shown in Table 1 are data on degree awards by institutional type.

There was only one very large institution in the earliest period shown, 1977-1979, but the number grew to 17 by the most recent period. These institutions had median federal R&D expenditures for engineering of $70.9 million per year and produced about 213 PhDs per year, on average, between 2013 and 2015. In 1977-1979 there were just four large engineering schools; this number had grown more than six-fold by the 2013-2015 period. These large institutions produced an average of just less than half as many PhDs annually (approximately 91) than did the very large institutions and received about $45.1 million in R&D funds for engineering each year in 2013-2015.

Conclusion

The twentieth century was marked with revolution and transformation, on many levels and for many domains- perhaps none more so than the educational system, which supports an educated, skilled population. While this particular paper did not explore causal links between funding, policy, and demographic changes in engineering programs- several compelling correlations emerged, providing the basis for further research into the complex relationship between federal post-secondary education funding, changing demographics (including gender, ethnicity, and nativity), and human capital. This paper found that immigration policy changes with the rise of temporary resident students included women in engineering. These temporary resident women were an important component of the increased presence of women among U.S. engineers in recent cohorts of PhD recipients, as temporary residents of both genders came to represent a larger share of engineering PhD recipients from U.S. universities.

Expansion of engineering in higher education, at the time when the Federal government was making investments in facilities and faculty quality, meant that there was an expansion in doctoral degrees awarded in engineering, as might be expected. As in other fields, the engineering doctoral degree provides a research-oriented toolkit for engineers, enabling movement from highly applied, technical work in industrial and government settings into research positions in those same sectors, in addition to entrée into academic careers.

The unexpected finding of a lack of a correlation between federal funding and increasing temporary resident PhD recipients suggested that mid-tier doctorate institutions appeared to provide the best point of entrée for non-citizen engineering students. Perhaps mid-tier institutions rely on increasing enrollment of temporary resident students as a growth strategy to supplement lower federal funding levels? Or maybe international students pay a larger percentage of tuition, or work as teaching assistants (rather than as research assistants supported by external funds) in exchange for tuition remission? Such questions suggest directions for future research. The weak (or non-existent) relationships between the percentage of women and R&D funding

The role of specific programmatic interventions in the demographic composition of engineering PhDs is another area for future study. Just as

other researchers have examined the impact of the doubling of NIH funding on production of PhDs in the biomedical sciences (Blume-Kohout 2012, Diaz et al 2012, and Frehill 2016), similar analyses of the trends described in this article could be completed. NSF-funded programs such as the Alliance for Minority Participation "Bridge to the Doctorate" supplements, the Alliance for Graduate Education and the Professoriate, and the NSF Advance: Institutional Transformation[7] program may have affected the pools of graduate students and production of PhDs starting in the early part of the 21st century. Such analyses, however, require careful analyses to avoid over-stating program effects, given the larger social context in which they were embedded.

Overall, this paper concludes that there is some relationship between federal funding of post-secondary education and macro-level demographic changes. We also conclude that these changes are associated with increases in female representation in engineering PhD degree production. A limitation of this paper is the lack of further discussion of the actual effect, strength, and significance of this relationship. We plan to address these aspects through further research. This paper represented an exploratory look into the complicated and complex dynamics of federal funding, human capital, and changing demographics in PhD degree production. These initial findings have supported the formation of an initial research agenda to further pursue more detailed analyses of these variables and how these relationships can be better understood and leveraged to support continued and increase representation of women in the U.S. engineering enterprise.

Conflict of Interest

The author declares that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Acknowledgments

I thank Katie Seely-Gant, who provided research support for earlier versions of this paper. The author is grateful to the three anonymous reviewers, whose comments helped us improve the manuscript.

[7] The Advance program is focused on faculty composition rather than the gender composition of graduate degree cohorts.

References

"The Competitiveness and Innovative Capacity of the United States." edited by U.S. Department of Commerce, 160. Washington, D.C., 2012.

"H-1b Visa Program: Reforms Are Needed to Minimize the Risks and Costs of Current Program." Washington, D.C.: U.S. Government Accountability Office (GAO), 2011.

"Policy Implications of International Graduate Students and Postdoctoral Scholars in the United States." Washington DC: The National Academies Press 2005.

"Beyond Bias and Barriers: Fulfilling the Potential of Women in Academic Science and Engineering." Washington, D.C.: The National Academies Press 2007.

"Gender Differences at Critical Transitions in the Careers of Science, Engineering, and Mathematics Faculty." Washington, D.C.: The National Academies Press 2010.

"Seeking Solutions: Maximizing American Talent by Advancing Women of Color in Academia: Summary of a Conference." Washington, D.C.: The National Academies Press 2013.

Atkinson, R. D., and Merrilea Joyce Mayo. "Refueling the US Innovation Economy: Fresh Approaches to Science, Technology, Engineering and Mathematics (STEM) Education." The Information Technology & Innovation Foundation, Forthcoming (2010).

Bishop, John. "The Effect of Public Policies on the Demand for Higher Education." *Journal of Human Resources* (1977): 285-307.

Black, Grant C., and Paula E. Stephan. "The Economics of University Science and the Role of Foreign Graduate Students and Postdoctoral Scholars." In American Universities in a Global Market, edited by Charles T. Clotfelter, 129 - 61: University of Chicago Press, 2010.

Blume-Kohout, Meg. "Effects of Changes in NIH Funding on PhD Enrollments and Completions in Biomedical Sciences." In NIH SWAM Meeting, 29: Center for Health Policy at the University of New Mexico, 2012.

Board, National Science. "Higher Education in Science and Engineering." In Science and Engineering Indicators 36. Washington, D.C.: National Science Foundation, 1998.

Brandi, Carolyn, Andrew Frampton, Lisa M. Frehill, and M. Amanda Lain. 2010. Salaries of Engineers, Scientists, and Technicians: A Guide to Starting Salaries and Career Advancement. (Washington, DC: Commission on Professionals in Science and Technology).

Chander, Parkash, and Shandre M. Thangavelu. "Technology Adoption, Education and Immigration Policy." *Journal of Development Economics* **75**, no. 1 (2004): 79-94.

Corbett, Christianne and Catherine Hill. Solving the Equation: The Variables for Women's Success in Engineering and Computing. Washington, DC: American Association of University Women, (2015).

Corley, Elizabeth A., and Meghna Sabharwal. "Foreign-Born Academic Scientists and Engineers: Producing More and Getting Less Than Their U.S.-Born Peers?" *Research in Higher Education* **48**, no. 8 (2007): 909-40.

Cressey, Daniel. "PhDs Leave the Ivory Tower." *Nature News* **484**, no. 7392 (2012): 1.

Diaz, Mauricio Gomez, Navid Ghaffarzadegan, and Richard Larson. "Unintended Effects of Changes in NIH Appropriations: Challenges for Biomedical Research Workforce Development." Massachusetts Institute of Technology, Engineering Systems Division, Technology and Policy Program, 2012.

Ehrlich, Everett. "An Economic Engine NIH Research, Employment, and the Future of the Medical Innovation Sector." 20: United for Medical Research, 2012.

Engineering, National Academy of. The Importance of Engineering Talent to the Prosperity and Security of the Nation: Summary of a Forum. Edited by Steve Olson. Washington, DC: The National Academies Press, 2014.

Federation of American Societies for Experimental Biology (FASEB). "NIH Research Funding Rebounds in President's FY 2016 Budget." In NIH Research Funding Trends 2. Bethesda, MD: Federation of American Societies for Experimental Biology, 2015.

———. "Testimony of the Federation of American Societies for Experimental Biology on FY 2014 Appropriations for the National Institutes of Health." Bethesda, MD: Federation of American Societies for Experimental Biology, 2013.

Finn, Michael G. "Stay Rates of Foreign Doctorate Recipients from U.S. Universities, 2011." In Science Education Programs. Oak Ridge, TN: Oak Ridge Institute for Science and Education, 2014.

Frehill, Lisa M. “The Role of International Women in the Expansion of the Biomedical Postdoc Workforce” pp. 131-149 in Branch, A.H. Reconsidering the Pipeline? Pathways, Potholes, and the Persistence of Women in STEM Fields. (Lanham, MD: Rowman & Littlefield), 2016.

Frehill, Lisa M. "Gender and Career Outcomes of Us Engineers." *International Journal of Gender, Science and Technology* **4**, no. 2 (2012): 148-66.

Frehill, Lisa M. “Salaries of Engineers” (White Plains, NY: National Action Council for Minorities in Engineering, Inc.) (2011).

Frehill, Lisa M. "Ph.D. Completion for Engineers." In Women in Engineering: A Review of the 2008 Literature, SWE Magazine, (2009).

Frehill, Lisa M., Nicole M. DiFabio, and Susan T. Hill. Confronting the “New” American Dilemma: Underrepresented Minorities in Engineering, a Data-Based Look at Diversity. (White Plains, NY: National Action Council for Minorities in Engineering, Inc.), 2008.

Frehill, Lisa M. "The Gendered Construction of the Engineering Profession in the United States, 1893-1920." *Men and Masculinities* **6**, no. 4 (2004): 383-403.

Frehill, Lisa M. “Women of Color in the Engineering Pipeline” Proceedings of the 2004 WEPAN Conference, Albuquerque, NM (2004).

Frehill, Lisa M., and Nicole M. Di Fabio. "Financing Graduate Education." In Commission on Professionals in Science and Technology.

Frehill, Lisa M. “Evaluator’s Report: New Mexico Alliance for Graduate Education and the Professoriate”. (Las Cruces, NM: Technical Report), 2003.

Gambino, Christine, and Thomas Gryn. "The Foreign Born with Science and Engineering Degrees: 2010. American Community Survey Briefs. Acsbr/10-06." US Census Bureau (2011).

Goldin, Claudia, and Lawrence F. Katz. "Human capital and social capital: the rise of secondary schooling in America, 1910–1940." *Journal of interdisciplinary history* **29**, no. 4 (1999): 683-723.

Group, Optimal Solutions. "Literature Review and Analysis Documenting the Impact of Scientific Workforce Diversity on the Scientific Enterprise and the Public Good." 74. College Park, MD, 2011.

Hill, Catherine, Christianne Corbett, and Andresse St. Rose. Why So Few?: Women in Science, Technology, Engineering and Mathematics. (Washington, DC: American Association of University Women), 2010.

Hira, Ronil. "Policy and the STEM Workforce System." STEM Workforce Data Project: Report No 9 (2007).

Kanny, Mary Allison, Linda J. Sax, and Tiffani A. Riggers-Piehl. "Investigating forty years of STEM research: How explanations for the gender gap have evolved over time." *Journal of Women and Minorities in Science and Engineering* **20**(2): 127-148, 2014.

Kelly, Eamon M. F. Albert Cotton, Diana S. Natalicio, M.R.C. Greenwood, Richard Tapia, and Jean M. Pomeroy. "The Federal Role in Science and Engineering Graduate and Postdoctoral Education." In Task Force on NSB October 1997 Meeting: The National Science Board, 1998.

Kessel, Cathy. "Understanding Underrepresentation: Women in Mathematics and Other Fields." 1-16. The Mathematical Intelligencer. 2014.

Kohlstedt, Sally Gregory. "Sustaining Gains: Reflections on Women in Science and Technology in 20th-Century United States." *NWSA Journal* **16**, no. 1 (2004): 1-26.

Langdon, David, George McKittrick, David Beede, Beethika Knah, and Mark Doms. 2011. "STEM: Good Jobs Now and for the Future" ESA Issue Brief #03-11 (July), (Washington, DC: U.S. Department of Commerce, Economics and Statistics Administration).

Litzler, Elizabeth, Sheila Edwards Lange, and Suzanne G. Brainard. "Climate for Graduate Students in Science and Engineering Departments." Paper presented at the Proceedings of the 2005 American Society for Engineering Education annual conference & exposition, 2005.

Lowell, Lindsay, Micah Bump, and Susan Martin. "Foreign Students Coming to America: The Impact of Policy, Procedures, and Economic Competition." ISIM Georgetown University, Project Summary Report (2007).

Lowry, Richard. "Significance of Difference Between Two Correlation Coefficients," Concepts and Applications of Inferential Statistics. [Online at http://vassarstats.net/textbook/ (4 August 2017)].

Malcom, Shirley M., P. Hall, & J. Brown. 1976. "The Double Bind: The Price of Being a Minority Woman in Science." (Washington, DC: American Association for the Advancement of Science).

National Defense Education Act, P.L. 85-864, 20 U.S.C., 72 Stat. 1580 (1958).

National Science Foundation, National Center for Science and Engineering Statistics, Survey of Research and Development at Universities and Colleges, (WebCASPAR) (https://webcaspar.nsf.gov) [16 Jan. 2017].

National Science Foundation, National Center for Science and Engineering Statistics, Survey of Earned Doctorates, (WebCASPAR) (https://webcaspar.nsf.gov) [30 Jan. 2017].

National Science Foundation, National Center for Science and Engineering Statistics, Integrated Science and Engineering Resources Data System Completions by Race (WebCASPAR) (https://webcaspar.nsf.gov) [16 Jan. 2017].

Okahana, H., & Zhou, E. (2019). International graduate applications and enrollment: Fall 2018. Washington, DC: Council of Graduate Schools.

Regets, Mark C. and Jean M. Johnson. "International Mobility of Scientists and Engineers to the United States- Brain Drain or Brain Circulations?", edited by Directorate for Social National Science Foundation, Behavioral, and Economic Sciences. Arlington, VA, 1998.

Romer, Paul M. Should the Government Subsidize Supply or Demand in the Market for Scientists and Engineers? Edited by Adam B. Jaffe, Josh Lerner and Scott Stern. Vol. 1, Innovation Policy and the Economy. National Bureau of Economic Research: MIT Press, 2001.

Stephan, Paula E., Albert J. Sumell, Grant C. Black, and James D. Adams. "Doctoral Education and Economic Development: The Flow of New Ph.D.S to Industry." *Economic Development Quarterly* **18**, no. 2 (2004): 151-67.

Technology, President's Council of Advisors on Science and. "Transformation and Opportunity: The Future of the U.S. Research Enterprise." edited by Executive Office of the President, 124. Washington, D.C.: Government of the United States of America, 2012.

Toner, P. "Workforce Skills and Innovation: An Overview of Major Themes in the Literature " In OECD Education Working Paper series: OECD Directorate for Science, Technology and Industry, 2011.

Wasem, Ruth Ellen. "Immigration of Foreign Nationals with Science, Technology, Engineering, and Mathematics (Stem) Degrees." 2012.

Waters, Mary C., and Karl Eschbach. "Immigration and Ethnic and Racial Inequality in the United States." *Annual Review of Sociology* **21**, no. 1 (1995): 419-46.

Williams, Joan C., Katherine W. Phillips, and Erika V. Hall (2014). "Double Jeopardy? Gender Bias Against Women of Color in Science" (San Francisco, CA: UC Hastings College of Law, WorkLifeLaw).

Bio

Lisa M. Frehill has been a senior analyst at Energetics Technology Center since 2010, which included support to the Assistant Secretary of Defense for Research and Engineering's STEM Development Office and to the National Science Foundation. Her research focuses on science and engineering human resource issues, with an emphasis on gender, diversity, and inclusion issues.

Ancient River Morphological Features on Mars versus Arizona's Moenkopi Plateau

Antonio J. Paris & Laurence A. Tognetti

Planetary Sciences, INC.

ABSTRACT

Mars is currently at the center of scientific debate regarding proposed ancient river morphological landscapes on the planet. An increased curiosity in the geomorphology of Mars and its water history, therefore, has led to an effort to better understand how those landscapes formed. Many studies, however, consist of patchwork investigations that have not thoroughly examined proposed ancient fluvial processes on Mars from an Earth-analog perspective. The purpose of this investigation, therefore, is to compare known fluvial features on Moenkopi Plateau with proposed paleopotamologic features on Mars. The search for analogs along the Moenkopi Plateau was due to the similarities in fluvial erosion, influenced and modified by eolian (wind) activity, primarily from Permian through Jurassic age. By analyzing orbital imagery from two cameras onboard NASA's Mars Reconnaissance Orbiter (MRO) - the High-Resolution Imaging Science Experiment (HiRISE) and the Context Camera (CTX) - and paralleling it with imagery obtained from the U.S. Geological Survey and an unmanned aircraft operating over the Moenkopi Plateau, this investigation identified similar fluvial morphology. We interpret, therefore, that the same fluvial processes occurred on both planets, thereby reinforcing the history of water on Mars.

PROPOSED FLUVIAL FORMATIONS ON MARS

The history of water on Mars is a matter of contention, and one of the essential questions planetary scientists are attempting to unravel. The *Kasei Valles*, for illustration, is a vast system of canyons in the *Mare Acidalium* and *Lunae Palus* quadrangles on Mars, centered at latitude 24.6° N and longitude 65.0° W (Figure 1). The canyons are ~1,580 km long and represent one of the largest proposed outflow channel systems on the planet.[1] Numerous studies have attempted to interpret the troughs and valleys of *Kasei Valles* as incontrovertible outflow channels, but their history and origin remain ambiguous. Surface features in the region appear to represent an outflow area that could have been the result of catastrophic flooding millions of years ago. Proposed paleopotamologic features in *Kasei Valles*, such as tributaries, terraces, flood plains, and streamlined islands, appear

analogous to known fluvial features found on the Moenkopi Plateau, which were shaped by the flow of water. Others proposed that glacial action or volcanic activity produced the paleopotamologic features on Mars, rather than the flow of liquid water.[2]

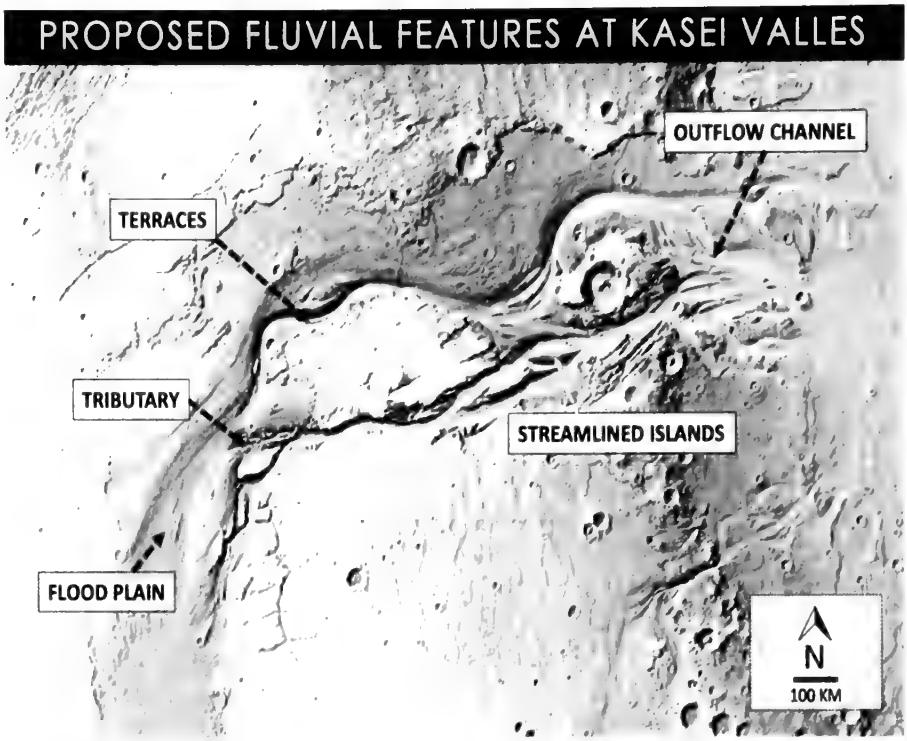


Figure 1: Proposed fluvial features created by the flow of water. Source: NASA Mars Orbiter Laser Altimeter

MOENKOPI PLATEAU

This investigation focuses on the Moenkopi Plateau in northeastern Arizona (Figure 2). The area extends from the Little Colorado River northeastward to the summit, covering 484 km^2. Elevations range from 1,280 m at the Little Colorado River to 1,700 m on the plateau. The Adeii Eechii Cliffs, an erosional scarp, demarcates the southwest edge of the Moenkopi Plateau. Other major erosional scarps to the southwest include the Red Rock Cliffs and Ward Terrace.[3]

Geomorphic interactions between eolian and fluvial processes since the late Pleistocene are reflected by drainage patterns on northeasterly plunging sedimentary rocks and by the northeastward withdrawal of cuestas along the southwest boundary of the plateau.[3] Tributary drainages, such as the Five Mile, Landmark, Tonahakaaad, Tohachi, and Gold Spring Wash,

flow southwestward from the edge of the plateau toward the Little Colorado River. Subsequent fluvial drainages, moreover, are entrenched within resistant strata near the base of retreating scarps, leaving a visual record of scarp retreat and development during the past ~2.4 million years.[4] During the Pliocene, wind-swept sand from indigenous sedimentary strata was

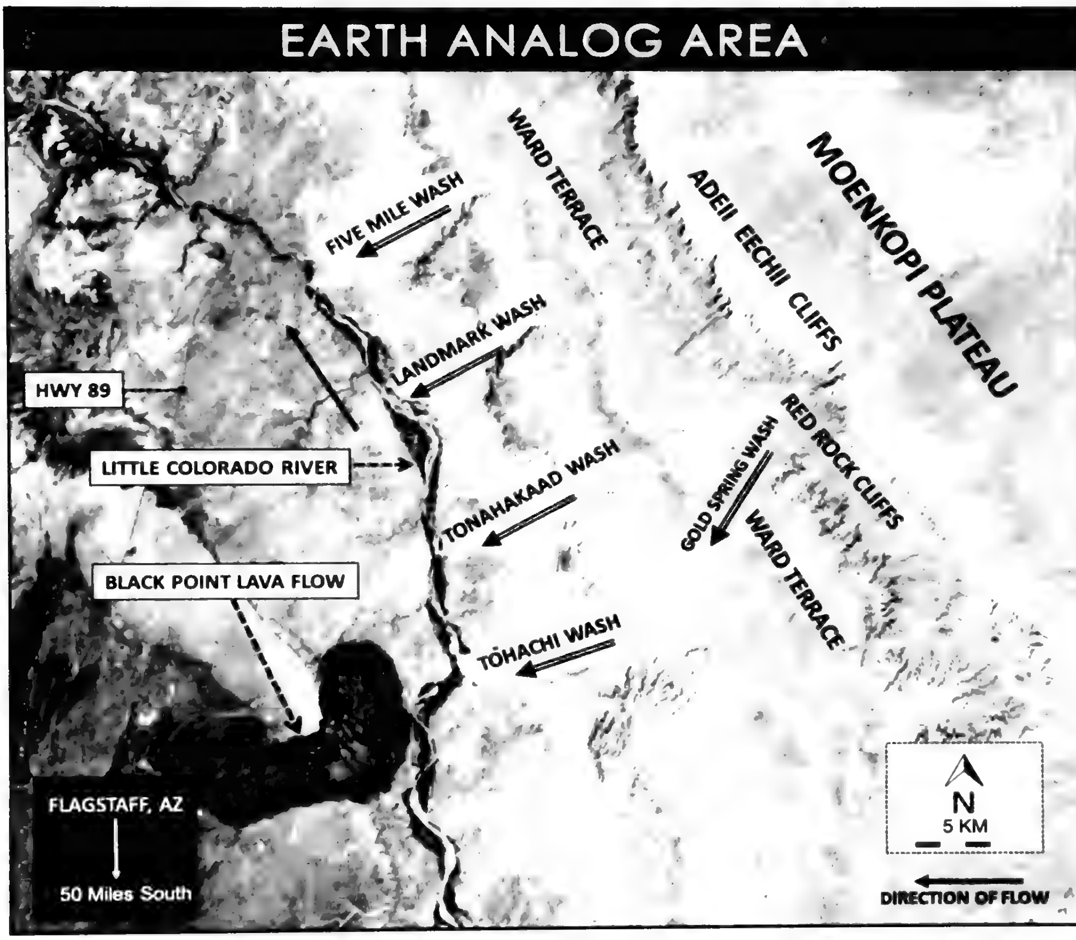


Figure 2: The Moenkopi Plateau. Source: USGS

transported from Little Colorado in the southwest onto the Moenkopi Plateau in the northeast, opposite of the direction of fluvial flow.

As noted above, the age of present fluvial and eolian deposits in the analog area is Holocene and Pleistocene, undivided.[5] Geologically, the plateau consists of exposed sedimentary rocks of Permian through Jurassic; volcanic basalt deposits from the Black Point lava flow; and surficial deposits consisting of sand dunes, sand sheets and landside deposits (Figure 3). Sedimentary rocks that consist of silica-cemented sandstone, interbedded limestone, and multi-colored shale plunge to the northeast and form

northwest-trending ledges and cliffs. The bedrock in the area of study, moreover, has been eroded by streams, winds, and a copious supply of loose sediment available for redeposition.[6]

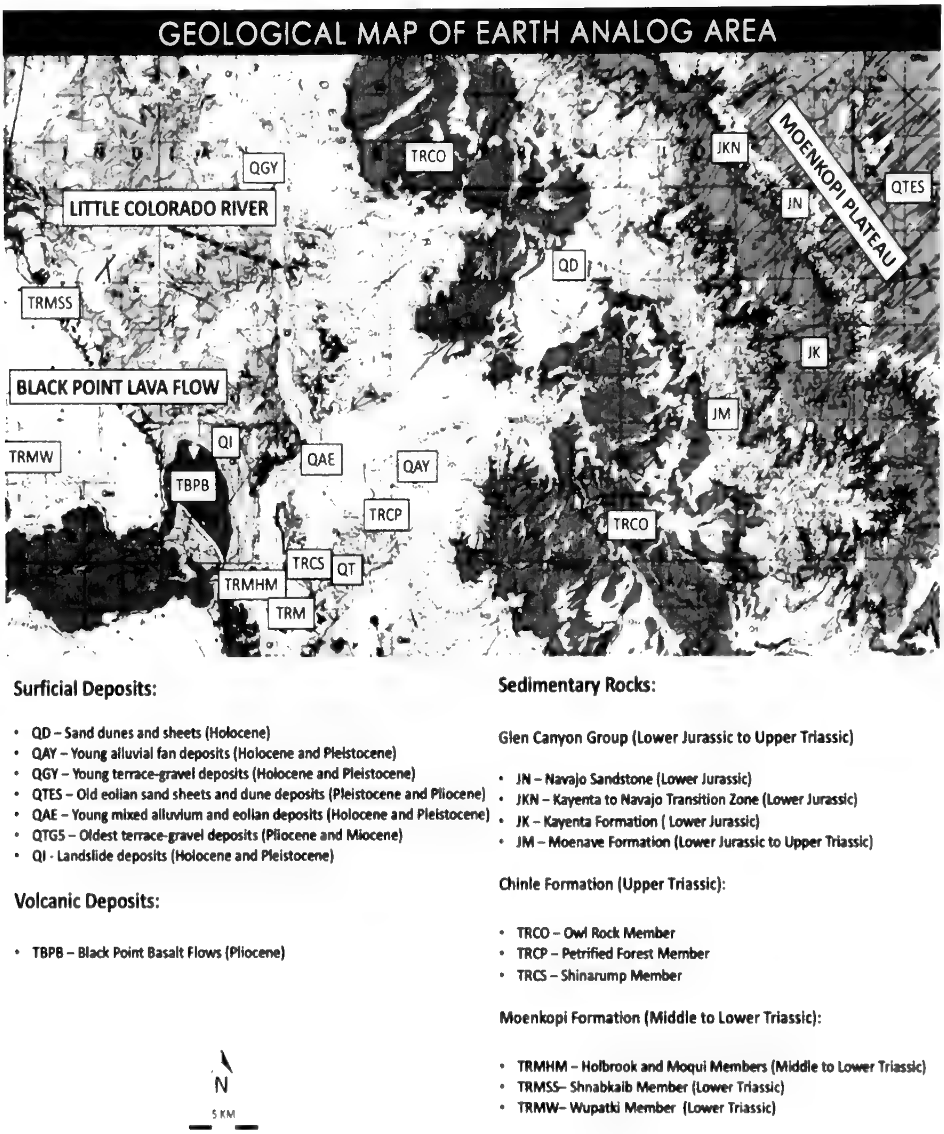


Figure 3: Geological Survey of the Moenkopi Plateau. Source: USGS and Planetary Sciences, Inc.

GEOMORPHOLOGY OF FLUVIAL SYSTEMS ON EARTH

Fluvial systems, the most significant geomorphic agent on Earth, are primarily dominated by streams and rivers. For millions of years fluvial processes have sculpted, eroded, and transported sediment to create new landforms. The watershed or drainage basin is a fundamental landscape component in fluvial geomorphology and consists of a parent river and its

tributaries.[7] The rivers, streams, and the depositional and erosional behavior of fluvial systems produce a variety of geomorphic topographies along the floodplain, such as meandering systems, tributaries, terraces, oxbows, confluence, braiding, cut banks, point bars, streamlined islands, and terraces (Figure 4). Erosion, which originates from the power and consistency of the current, can affect the formation of the river's path.[8] Furthermore, the availability, rate of deposition, size, and composition of sediment moving through the channel will shape and change the direction of the river over time.[9] Dunes and sand sheet deposits due to eolian activity further contribute to the morphology of the Moenkopi Plateau.

Today, stream deposits between the Little Colorado River and the Moenkopi Plateau consist mostly of mud, silt sand, and gravel. Throughout seasonal dry spells in late spring and early summer, sand and silt travel in the wind from stream channels, primarily Tohachi Wash (Figure 2), onto adjacent flood plains.[3] Most of the sand occurs in sheets that advance northeasterly. Where the sand is relatively thin or sparse, it forms well-defined barchan or parabolic dunes while thicker sand sheets form complex dunes.[10] Some of the sand blown by the wind from washes, however, is transported by streams back into the washes. This recycling takes place in all drainages east of the Little Colorado River regardless of their orientation.[11]

DATA COLLECTION

ORBITAL IMAGERY OF MARS AND IMAGERY OF THE MOENKOPI PLATEAU

The NASA HiRISE and CTX imagery used in this investigation were available through NASA's Planetary Data System (PDS) and the Lunar and Planetary Laboratory, University of Arizona. HiRISE can see the surface of Mars with a high-resolution capability up to ~30 centimeters per pixel, while the MRO CTX camera can observe at ~6 meters per pixel.[12] MRO also observes the Martian surface earlier in the day; thus, more geomorphic features are evident with partially sunlit floors.[13] A partially sunlit floor allows planetary scientists to identify specific features characteristic to paleofluvial action and floor morphologies, such as tributaries, terraces, flood plains, and streamlined islands. The data for Martian surface composition and properties came from the Thermal Emission Spectrometer (TES) onboard the Mars Global Surveyor spacecraft, which is accessible

through the Java Mission-planning and Analysis for Remote Sensing (JMARS). The database is a geospatial information system (GIS) developed by ASU's Mars Space Flight Facility to provide mission planning and data-analysis tools to NASA scientists and instrument team members. Global mineral abundance maps were derived using atmospherically corrected TES spectral data and a suite of 36 endmembers, and interpolation used between adjacent orbit tracks.[14] The MRO images (HiRISE and CTX) were then compared with imagery obtain through the use of a crewless aerial vehicle (UAV) operated by Planetary Science, Inc. *in situ* on the Moenkopi Plateau. The UAV offered a powerful camera on a 3-axis stabilized gimbal that recorded video at 4k resolution up to 60 frames per second and featured real-glass optics that captured aerial imagery at 12 megapixels from an altitude up to 800 m and a range of 7 km.[15] Data obtained from the U.S. Geological Survey Earth Explorer (EE) imagery interface for high altitude aerial imagery also provided remote sensing inventory of the Moenkopi Plateau.

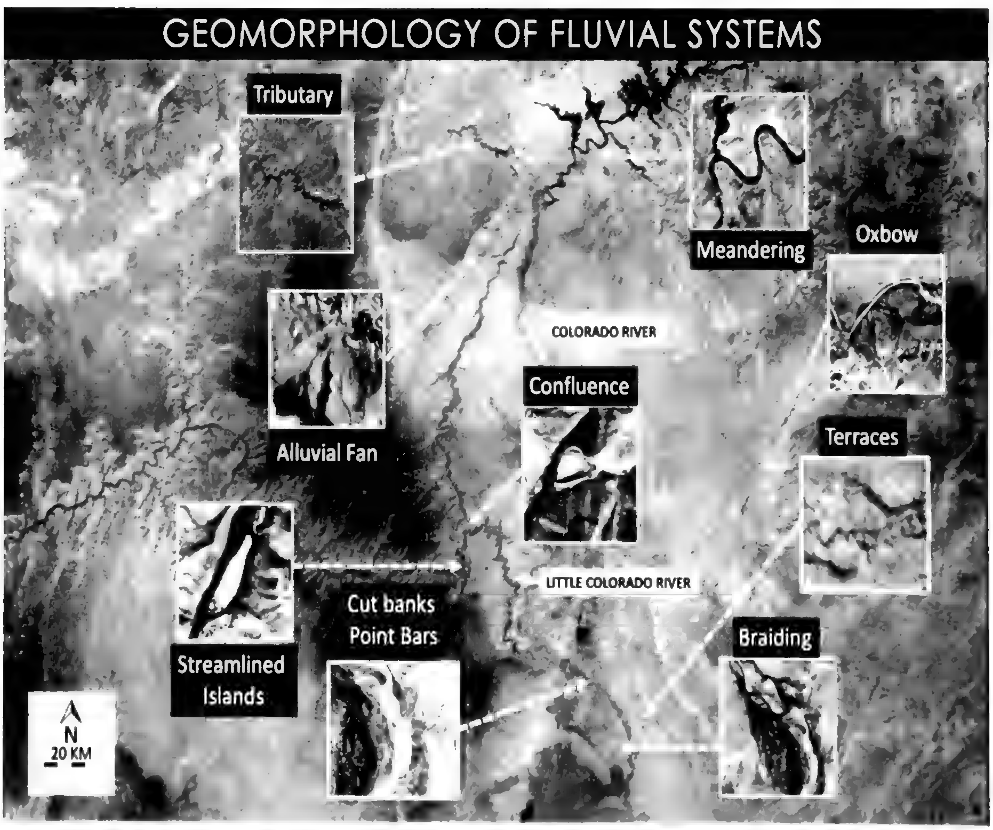


Figure 4: Examples of Fluvial Morphology. Source: USGS and Planetary Sciences, Inc.

IMAGERY ANALYSIS & INTERPRETATION

In Appendix 1, we present a series of orbital imagery of *proposed* paleopotamologic formations on Mars alongside aerial imagery of *known* fluvial morphology on the Moenkopi Plateau. The images infer that known fluvial processes that occur on the Moenkopi Plateau also took place on Mars early in its history. As the two planets are comparable compositionally, their rocks and minerals have similar names.[16] The shape and size of geomorphic processes on Mars, however, depend mostly on a set of environmental conditions and properties dissimilar to Earth. Lesser atmospheric pressure altered the scattering of material, and lower gravity facilitated wider dispersion.[17] Consequently, fluvial artifacts on Mars are larger than their terrestrial analogs.

ANALOG 1: TRIBUTARY

A tributary is a stream or river that does not flow directly into a sea or ocean. In this fluvial setting, as exhibited in Figure 5, the water in both tributaries flowed into a more significant stream, parent river, or channel. These waterways, including the main stem river, drain the neighboring drainage basin of its surface water and groundwater, leading the water out into an ocean.[18] The tributary located in the western region of *Nilus Mensae* (latitude 22.102° N and longitude 287.570° E) is of the ~4 billion-year Noachian age, undivided, and characterized by canyons and channel floors similar to the tributaries in the Moenkopi Plateau. The *Nilus Mensae* area is a highland transition unit dominated by complex admixtures of impact, sedimentary, and volcanic rocks; it primarily consists of basalt, andesite, and traces of feldspar, hematite, and quartz.[19] The tributary investigated in the Moenkopi Plateau (latitude 35° 43’ 45” N and longitude 111° 18’ 51” W) is of Holocene to Pleistocene age. The area is dominated by deposits of basaltic ash fragments, quartz, feldspar, gray-brown chert, quartz sandstone grains, and quartz with iron inclusions.[3]

ANALOG 2: CONFLUENCE

A confluence or conflux occurs where two or more flowing bodies of water intersect to form a single river or where a tributary or wash joins a parent river or channel.[20] The natural flow of confluences gives rise to hydrodynamic patterns, such as mixing layers, stagnation zones, and shear layers, which, in some instances, can be identified from orbital and aerial

imagery. Denser materials transported by either flow, such as large pebbles and rocks, sink to the main river bottom at or downstream of the confluence and amalgamate into deposits.

Dao Vallis, a proposed outflow channel on Mars, is of the warmer wetter ~3 billion year Hesperian age and runs southwestward into *Hellas Planitia* from the southern slopes of the volcano *Hadriacus Mons*. It and its tributary, *Niger Vallis*, extend for about 1,200 km.[21] Geologically, the area along the channel is comprised of planar deposits meters to tens of meters thick and tens to hundreds of kilometers across; flood lavas sourced from a regional fissure; and vent systems and lobate scarps are also typical.[22] Some proposed that *Dao Vallis* received water when hot magma from *Hadriacus Mons* melted vast amounts of ice in the frozen ground, released in massive outburst floods.[23] In one particular paleofluvial setting at *Dao Vallis* (latitude -36.804° S and longitude 89.990° E), settled mixing layers, stagnation zone, and shear layering can be identified (Figure 6). Telemetry from TES indicates an abundance of basalt, feldspar, and traces of quartz and hematite.[19] Conversely, the confluence examined on the Moenkopi Plateau (latitude 35° 43' 10" N and longitude 111° 08' 06" W) likewise arose from the convergence of two streams flowing southwestward from the Adeii Eechii Cliffs. The seasonal wash consists of a young mixture of alluvium fan deposits (Holocene and Pleistocene) dominated by clear quartz, milky quartz, light-red quartz, blue-gray chert, and fragments of basaltic ash fragments and schist.[3] Owl Rock, Chinle Formation (Upper Triassic), borders the rivers.

ANALOG 3: STREAMLINED ISLANDS

Streamlined or teardrop-shaped islands stand in the beds of most large outflow channels on Mars. These islands mark where rock outcrops made obstructions that successfully resisted the floods.[24] Along the flanks of some streamlined islands, ledges or benches develop. These indicate particularly resistant strata or where the flood maintained a depth long enough to erode the ledge or bench. After floodwaters divide around the obstruction, they progressively erode the ground behind it.[25]

Lying east of the volcanic region of *Tharsis*, *Kasei Valles* is the most significant proposed outflow channel on Mars. Similar to fluvial systems on the Moenkopi Plateau, the channels of *Kasei Valles* appear to have been

carved by liquid water, possibly during massive floods that originated in tectonic and volcanic activity in *Tharsis*.[24] Though larger than their terrestrial counterpart, streamlined islands are abundant at *Kasei Valles*. A particular streamlined island on *Kasei Valles* (latitude 24.736° N and longitude 311.401° E) unmistakably exhibits morphology consistent with the floodwater divide, including ledges and benches (Figure 7). This streamlined island of Noachian age is dominated by basalt, andesite, and traces of sulfate, feldspar, and carbonate. Additionally, the island is gradational with *Chryse Planitia* - a posited large lake or an ocean during the *Hesperian* or the subsequent cold dry *Amazonian* period.[19] The analogous streamlined island at the Moenkopi Plateau (latitude 35° 46' 08" N and longitude 111° 19' 30" W) is a stream-channel of Holocene age (Figure 7). The composition of bedrock samples along the streamlined island mainly consists of basaltic ash fragments, milky quartz, clear quartz, white quartz sandstone grains, and traces of magnetite and siltstone mud curls.[3] This analog, moreover, also exhibits ledges and benches consistent with fluvial erosion.

ANALOG 4: TERRACES

Terraces commonly appear on the banks of channels and rivers. Their presence indicates sufficient fluvial activity for erosion before the water receded. Terraces also could have been shaped by several layers of strata that resisted erosion better than the layers above or below.[24] There are a variety of terraces of different sizes along the channels of *Kasei Valles*. The channel located at latitude 23.829° N and longitude 295.544° E distinctly exhibits terracing steps consistent with fluvial morphology (Figure 8). These Noachian-age terraces feature basalt, andesite and traces of pyroxene, quartz, sulfate, olivine, sheet silicates, feldspar, carbonates, and hematite.[19] The terraces investigated on the Moenkopi Plateau (latitude 35° 45' 20" N and longitude 110° 56' 18" W) likewise exhibit several layers of erosion due to numerous stages of water flow. These terraces are part of the Navajo Sandstone, Glen Canyon Group laid down in the Lower Triassic and possibly Early Triassic.[6] The wide range of colors exposed along the Navajo Sandstone reflects a long history of modification by groundwater and other subsurface fluids over the last 190 million years.[26] The diverse colors originate from the presence of variable mixtures and amounts of hematite, goethite, and limonite that fill the pore space of the quartz sand in the Navajo Sandstone.[27]

ANALOG 5: ALLUVIAL FANS

Alluvial fans are triangular-shaped deposits of material transported by water. They are an example of unconsolidated sediment and tend to form in elevated regions with a rapid change in slope from a high to a low gradient.[28] The water flow transporting the sediment runs at a relatively high velocity due to the steep slope, which is why coarse material can remain in the stream. When the gradient decreases into a flat area, the fluvial action loses the energy it needs to transport the sediment further. The deposit eventually spreads out, forming an alluvial fan.[29]

Capri Chasma lies in the eastern portion of the *Valles Marineris*, the largest known canyon system in the Solar System. Deeply incised canyons such as *Capri Chasma* are exceptional targets for examining alluvial morphology, as many of the walls reveal distinct types of bedrock. *Capri Chasma is a* late Noachian highland comprised of undifferentiated impact, volcanic, fluvial, and basin material.[6] The alluvial fan located on *Capri Chasma* at latitude -13.354° S and longitude 308.285° E reveals how material was transported by water from a minor tributary to form the fan (Figure 9). Telemetry from TES at this particular fan shows abundant basalt and andesite with traces of quartz, sulfate, olivine, sheet silicates, feldspar, carbonates, and hematite.[19] The alluvial fan examined east of the Moenkopi Plateau (latitude 36° 12' 41" N and longitude 11123' 28" W) exhibits fluvial morphology analogous with the alluvial fan on *Capri Chasma*. In this geologically setting, water flowed from the top of the plateau through a series of stratigraphy (Kayenta Formation, Wingate Sandstone, and Chinle Formation) exposing fluvial siltstone, fine-grained silty sandstone with interbedded purplish-red shale and authigenic quartz.[3]

ANALOG 6: BRAIDING

A braided river is a network of river channels separated by small, often temporary, islands called braid bars. Braiding tends to occur in steeper slopes with high sediment loads.[30] Formations are common where water flow is slow, and there is a buildup of sediment in the river, causing changes in the direction of the river to create new, but often temporary, meandering channels.[31]

Marte Vallis is a valley in the *Amazonis Planitia* quadrangle of Mars, located at latitude 5.690° N and longitude 177.516° E. The valley is a proposed outflow channel, carved in the geological past by catastrophic release of water from aquifers beneath the Martian surface.[32] The valley displays noticeable braided flows analogous with those examined along the Tohachi Wash on the Moenkopi Plateau (Figure 10). Telemetry from TES at this particular flow reveals basalt and traces of sulfate, quartz, carbonates, feldspar, and hematite.[19] Conversely, the flow along the Tohachi Wash (latitude 35° 42' 41" N and longitude 111° 14' 07" W) similarly exhibits braided morphology, formed when water receding from the northeast slowed due to a buildup of sediment. Young terrace gravel, alluvium, and eolian deposits from Holocene and Pleistocene make up this braided river. Geologically, the river is dominated by clear quartz, basaltic ash fragments, siltstone mud curls, quartz sandstone grains and trace evidence of dark-red quartz, milky quartz, gray chert, biotite, gypsum, and schist fragments.[3]

ANALOG 7: OXBOWS

An oxbow is a crescent-shaped lake or river that forms when a vast meandering flow stops, creating a free-standing body of water or a U-shaped bend regardless of being cut off from the main waterway.[33] On the inside of the loop, the water travels more slowly, which leads to the deposition of silt. Meanwhile, water on the outside edges flows faster, which erodes the banks and widens the meander. Over time the loop of the meander expands until the neck disappears altogether.

Suggested meandering streambeds on *Aeolis Mensae* (latitude -5.58° S and longitude 153.551° E), for instance, exhibit a series of oxbow morphology analogous to those found on the Moenkopi Plateau (Figure 11). At *Aeolis Mensae*, some places on the stream show inverted relief, in which a stream bed could be a raised feature, rather than a valley. The inversion may be produced by the deposition of large rocks or by cementation that left the old channel as a raised ridge because the stream bed is more resilient to erosion.[34] Telemetry from TES at this particular oxbow reveals mostly traces of feldspar, sheet silicates, carbonates, and sulfate.[19] The oxbow on the Tohachi Wash (latitude 35° 51' 00" N and longitude 111° 11' 39" W), which is a member of the Glen Canyon Group (Lower to possibly Upper Triassic) is comprised of clear quartz, basaltic ash fragments, siltstone mud curls,

quartz sandstone grains and trace evidence of dark-red quartz, gray chert, biotite, and gypsum.[3]

ANALOG 8: CUT BANKS AND POINT BARS

In river morphology, as the water flows across the land, it erodes the soil and creates banks. Cut banks, in abundance along meandering streams, are located on the outside of a bend. They are cliff-shaped and molded by soil erosion as water flow collides with the river bank.[35] On the other hand, a point bar is a crescent-shaped depositional feature made of alluvium that accumulates on the inside of the bend. Point bars, like cut banks, are found in abundance in meandering streams and rivers.[36]

Cut banks and point bars are found along numerous channels on Mars, to include at *Hypanis Valles* (latitude 9.842° N and longitude 314.106° E). The *Hypanis Valles* are a set of channels in a 270-km valley in *Xanthe Terra* (Figure 12). The channels are burrowed between Middle Noachian highlands and feature volcanic, fluvial, undifferentiated impact, and basin materials. Some studies have proposed that long-lived flowing water carved these channels.[37] Telemetry from TES at this particular Martian oxbow reveals mostly silicon, iron, thorium and traces of quartz, feldspar, hematite, sulfate, potassium and chlorine. The Little Colorado River on the Moenkopi Plateau exhibits cut bank and point bar morphology analogous to the channels on *Hypanis Valles*. In a particular point along the Little Colorado River (latitude 35° 47' 35" N and longitude 111° 19' 05" W), a series of erosion and deposition activity along the inside and outside of the bends reveal how cut banks and point bars are formed (Figure 12). The composition of samples along these bends are predominantly basaltic ash fragments, milky quartz, clear quartz, white quartz sandstone grains and traces of magnetite and siltstone mud curls.[3]

CONCLUSION

An analysis of the HiRISE and CTX imagery of Mars has identified paleopotamologic features consistent with the visual record of the Moenkopi Plateau. Fluvial artifacts on Mars, such as tributaries, confluence, streamlined islands, terraces, alluvial fans, braided rivers, oxbows, cut banks, and point bars, were formed by the flow of water, as interpreted by the Earth analog. Moreover, accompanying fluvial interactions, such as drainage patterns, erosion, and deposition of sediments, are analogous on both planets.

This investigation, therefore, has resolved the contention regarding paleopotamologic artifacts on Mars by demonstrating that the fluvial landscapes were formed by water. Accordingly, earlier patchwork investigations proposing glacial action and/or volcanic activity as the mechanism behind these fluvial artifacts on Mars can be ruled out.

NOTES:

Though not conclusive or the primary purpose of our investigation, telemetry from TES and remote sensing data from the U.S. Geological Survey indicate that a particular mineral, quartz, has been detected on the alluvial features of Mars and the Moenkopi Plateau. Quartz is the second most copious mineral in the Earth's crust and forms in either igneous rocks or environments with geothermal waters. A recent study proposed that quartz found on Mars near *Antoniadi* Crater formed as a diagenetic product of hydrated amorphous silica, indicating there was once persistent water at *Antoniadi* Crater.[38]

BIO

Antonio Paris, the Principal Investigator (PI) for this study, is the Chief Scientist at Planetary Sciences, Inc., a former Assistant Professor of Astronomy and Astrophysics at St. Petersburg College, FL, and a graduate of the NASA Mars Education Program at the Mars Space Flight Center, Arizona State University. He is the author of "*Mars: Your Personal 3D Journey to the Red Planet*". His latest peer-reviewed publication includes *Prospective Lava Tubes at Hellas Planitia* – an investigation into leveraging lava tubes on Mars to provide crewed missions protection from cosmic radiation. Prof. Paris is a professional member of the Washington Academy of Sciences and the American Astronomical Society.

FIELD RESEARCH CONTRIBUTOR

Laurence A. Tognetti recently graduated from Arizona State University with a Master's Degree in Geological Sciences with thesis research focusing on geomorphological processes of the Martian surface. As a Field Researcher for the Planetary Sciences Inc., he operated the UAV in situ on the Moenkopi Plateau and assisted in imagery analysis.

APPENDIX 1

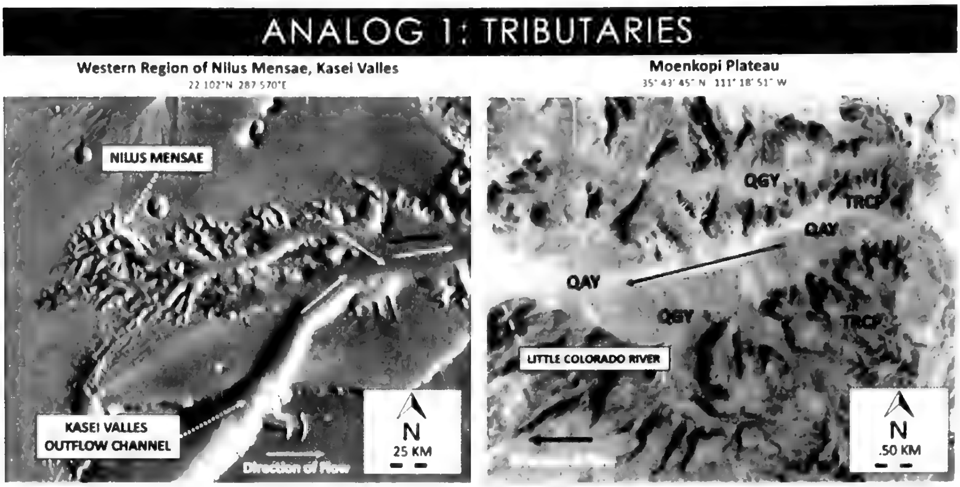


Figure 5: Nilus Mensae (Credit: NASA) and Moenkopi Plateau (Credit: Planetary Sciences, Inc. UAV)

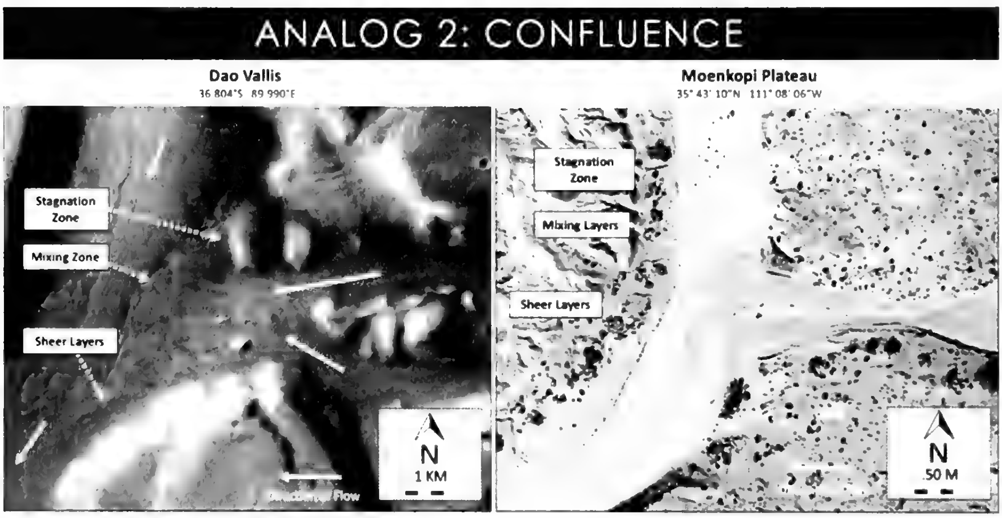


Figure 6: Dao Vallis (Credit: NASA) and Moenkopi Plateau (Credit: USGS)

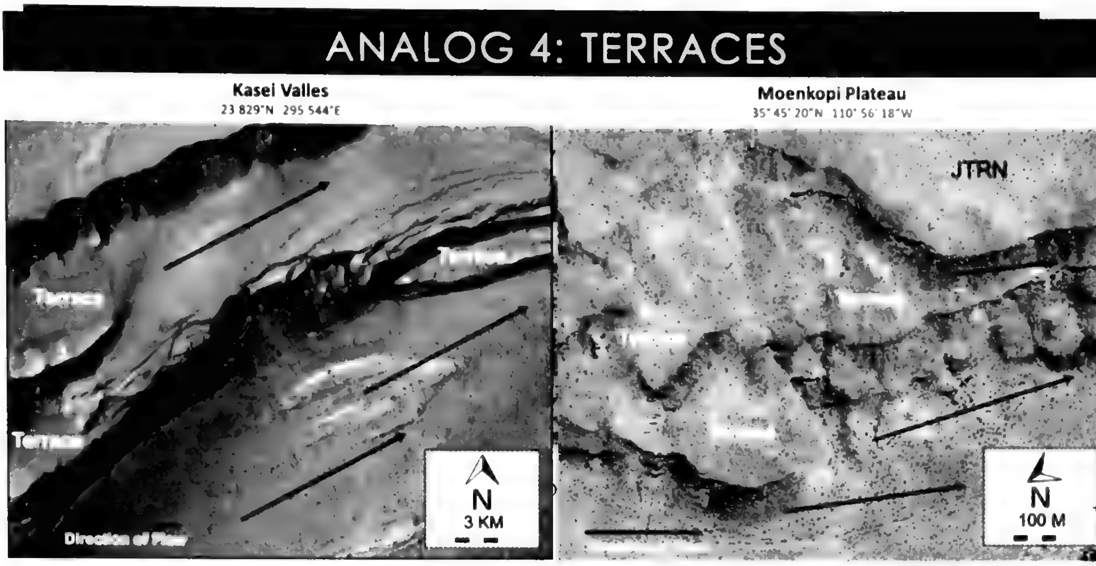


Figure 8: Kasei Valles (Credit: NASA) and Moenkopi Plateau (Credit: USGS)

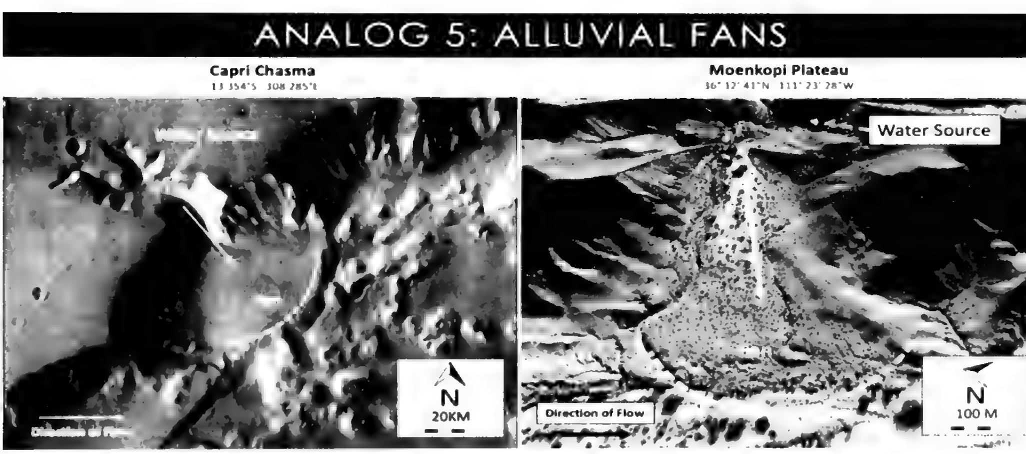


Figure 7: Capri Chasma (Credit: NASA) and Moenkopi Plateau (Credit: Planetary Sciences, Inc. UAV)

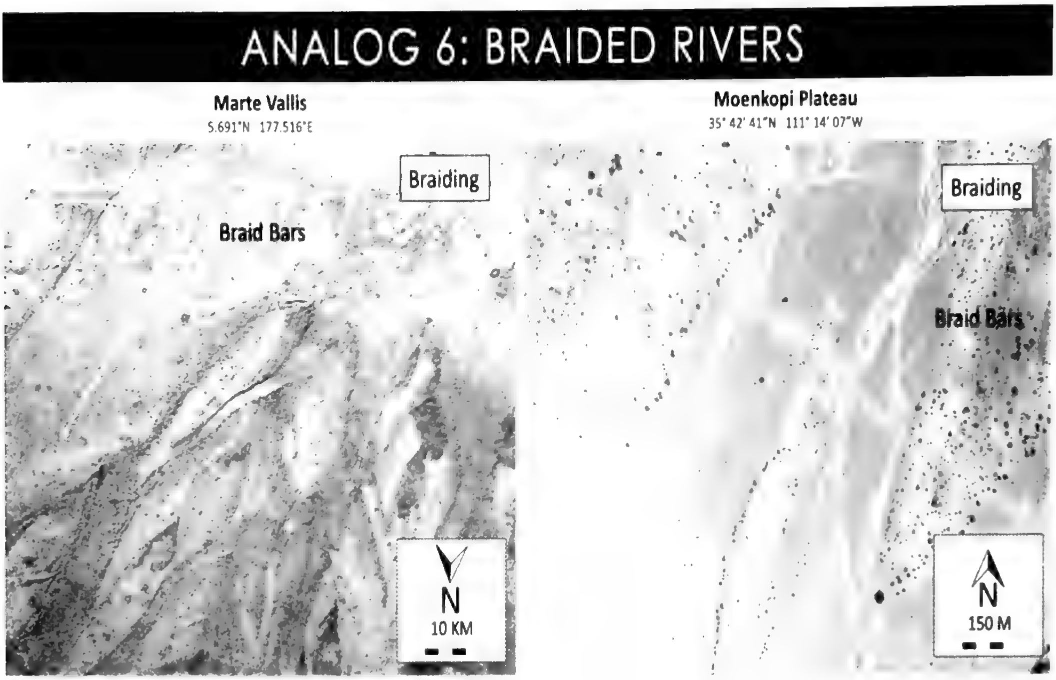


Figure 10: Marte Vallis (Credit: NASA) and Moenkopi Plateau (Credit: Planetary Sciences, Inc. UAV)

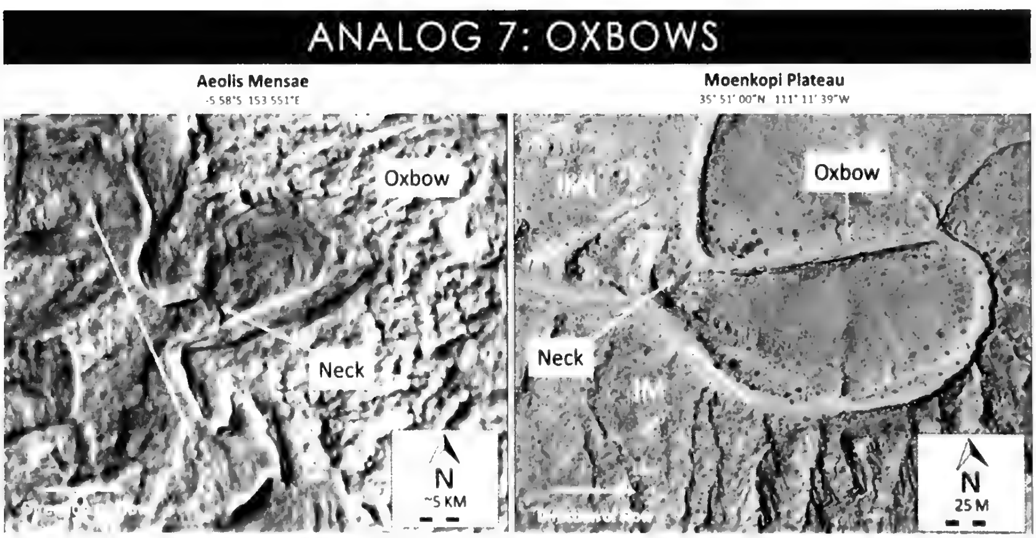


Figure 11: Aeolis Mensae (Credit: NASA) and Moenkopi Plateau (Credit: USGS)

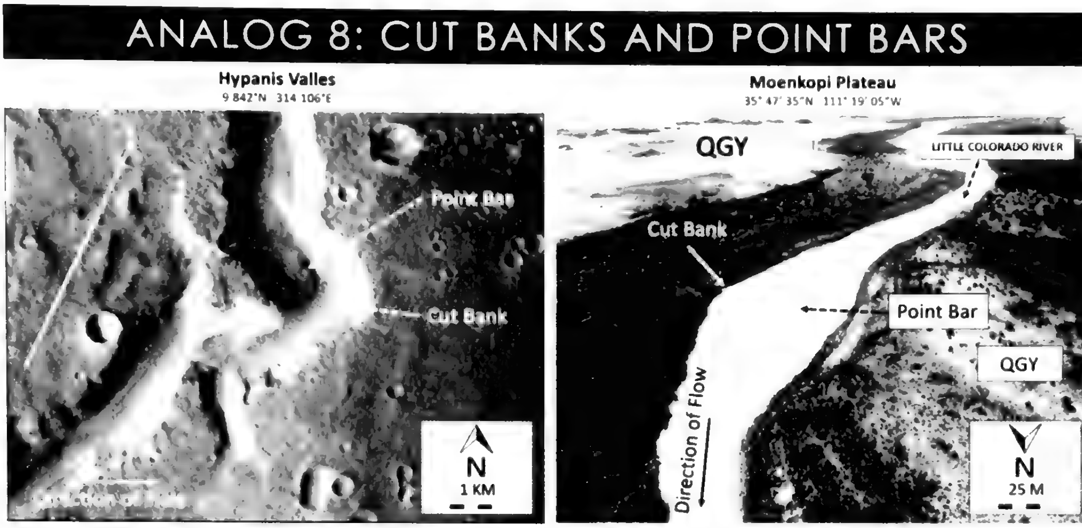


Figure 12: Hypanis Valles (Credit: NASA) and Moenkopi Plateau (Credit: Planetary Sciences, Inc. UAV)

REFERENCES

[1] Kasei Valles, Gazetteer of Planetary Nomenclature. U.S. Geological Survey Astrogeology Research Program (accessed at https://planetarynames.wr.usgs.gov/)

[2] Islands in Kasei Vallis, Mars Odyssey Mission THEMIS. School of Earth and Space Exploration, Arizona State University (accessed at https://themis.mars.asu.edu/zoom-20050427a

[3] Billingsley, G. H., 1987, Geology and Geomorphology of the Southwestern Moenkopi Plateau Arid Southern Ward Terrace, Arizona. U.S. Geological Survey. (available at https://pubs.usgs.gov/bul/1672/report.pdf)

[4] Tanner, L.H., 2007, The Moenave Formation: Sedimentologic and Stratigraphic Context of the Triassic–Jurassic Boundary in the Four Corners Area, Southwestern USA. Palaeogeography, Palaeoclimatology, Palaeoecology, Volume 244, Issues 1–4, Pages 111-125 (accessed at https://www.sciencedirect.com/science/article/abs/pii/S0031018206004445)

[5] Billingsley, G. H., 1987, Geologic Map of the Southwestern Moenkopi Plateau and Southern Ward Terrace, Coconino County, Arizona: U.S. Geological Survey Miscellaneous Investigations Series Map 1-1793, scale 1: 31,680 (accessed at https://www.azgs.arizona.edu/azgeobib/geologic-map-southwestern-moenkopi-plateau-and-southern-ward-terrace-coconino-county)

[6] National Geological Map Database, U.S. Geological Survey MapView (accessed at https://ngmdb.usgs.gov/mapview/)

[7] River Systems and Fluvial Landforms, National Park System (accessed at https://www.nps.gov/subjects/geology/fluvial-landforms.htm)

[8] Rosgen, D., 1996, Applied River Morphology, Wildland Hydrology Publishing, 2nd ed. ISBN-13: 978-0965328906

[9] Bo-Yuan Z, 2017, Aggravation of North Channels' Shrinkage and South Channels' Development in the Yangtze Estuary. Journal Estuarine, Coastal and Shelf Science 187 (accessed at https://www.sciencedirect.com/science/article/abs/pii/S0272771417300288?via%3Dihub)

[10] Fryberger, S.G., 1978, Techniques for the Evaluation of Surface Wind Data in terms of Eolian Sand Drift, U.S. Geological Survey Open-File Report 78-405, 25 p. (assessed at https://pubs.er.usgs.gov/publication/ofr78405)

[11] Childs, O.E., 1948, Geomorphology of the Valley of the Little Colorado River, Arizona: Geological Society of America Bulletin, v. 59, p. 353-388, 1 sheet, scale 1: 320,000

[12] HiRISE, School of Earth and Space Exploration, Arizona State University (accessed at https://www.uahirise.org/epo/about/

[13] Walden, B., 1998. Utility of Lava Tubes on Other Worlds, Workshop on Using in Situ Resources for Construction of Planetary Outposts, p. 16, (accessed at http://adsabs.harvard.edu/full/1998uisr.work...16W)

[14] Bandfield, J.L., 2012. Martian Global Surface Mineralogy from the Thermal Emission Spectrometer: Surface Emissivity, Mineral Map, and Spectral Endmember Data Products, Abstracts for the 6th Annual International Mars Society Conference

[15] EVO Drone Product Sheet (accessed at https://auteldrones.com/products/evo)

[16] Short, N. M., 1971. Volcanic Landforms and Surface Features: A Photographic Atlas and Glossary. New York: Springer, pp. 1–18., ISBN 978-3-642-65150-2

[17] Meresse, S., 2008. Formation and Evolution of the Chaotic Terrains by Subsidence and Magmatism, Hydraotes Chaos, Mars. Icarus. 194 (2): 487.

[18] Krebs, R. E., 2003. The Basics of Earth Science. Greenwood Publishing Group. ISBN 978-0-313-31930-3

[19] Internal Data Analysis, Thermal Emission Spectrometer, Java Mission-planning and Analysis for Remote Sensing (accessed through account portal from Arizona State University)

[20] Definition of Conflux by Merriam-Webster (accessed at merriam-webster.com)

[21] Crown, D. A., 2003. Geologic Evolution of Dao Vallis, Mars, American Geophysical Union, Fall Meeting 2003, abstract id. P11B-1035 (accessed at https://ui.adsabs.harvard.edu/abs/2003AGUFM.P11B1035C/abstract)

[22] Geologic Map of Mars, Scientific Investigations Map 3292, U.S. Geological Survey Astrogeology Research Program (accessed at https://pubs.usgs.gov/imap/i2782/)

[23] Dao Vallis, School of Earth and Space Exploration, Arizona State University (accessed at http://themis.asu.edu/zoom-20020807a)

[24] Mars Education Program, School of Earth and Space Exploration, Arizona State University (accessed at https://marsed.asu.edu/mep/water/channels/channel-flow-features)

[25] Fessler, B. Liquid Water on Mars, Mars Digital Image Map, Lunar and Planetary Institute (accessed at https://www.lpi.usra.edu/publications/slidesets/redplanet2/slide_25.html)

[26] Repenning, C. A., 1989. Stratigraphy of the Chinle and Moenkopi Formations, Navajo and Hopi Indian Reservations Arizona, New Mexico, and Utah. U.S. Geological Survey (accessed at https://pubs.usgs.gov/pp/0521b/report.pdf)

[27] Gregory, H.E., 1917. Geology of the Navajo Country; a Reconnaissance of parts of Arizona, New Mexico, and Utah. Professional Paper no. 93. U.S. Geological Survey, Reston, Virginia. 161 pp.

[28] Resource Library, National Geographic (accessed at https://www.nationalgeographic.org/encyclopedia/alluvial-fan/)

[29] American Geological Institute. Dictionary of Geological Terms. New York: Dolphin Books, 1962

[30] Sedimentology, Depositional Environments and Sequence Stratigraphy, Department of Geology and Environmental Science, James Madison University, (accessed at http://www.seddepseq.co.uk/DEPOSITIONAL_ENV/Fluvial/Braided/braided.htm)

[31] Definition, World Land Forms. (accessed at http://worldlandforms.com/landforms/braided-river/)

[32] Carr, M.H., 2006. The Surface of Mars. Cambridge Planetary Science Series, Cambridge University Press, ISBN:9780511536007

[33] Definition, MBG Resources (accessed at http://www.mbgnet.net/fresh/lakes/oxbow.htm)

[34] HiRISE Imagery, Sinuous Ridges Near Aeolis Mensae, School of Earth and Space Exploration, Arizona State University (accessed at https://www.uahirise.org/PSP_002279_1735)

[35] Marshak, S., 2009. Essentials of Geology, W. W. Norton & Company; Third Edition, ISBN: 978-0393932386

[36] Hickins, E.J., 2003. Meandering Channels, Encyclopedia of Sediments and Sedimentary Rocks, New York: Springer, p. 432 ISBN 1-4020-0872-4

[37] Crumpler L. S., New Mexico Museum of Natural History and Science, Albuquerque. NASA Workshop: Sites of Potential Long Term Sub-Surface Water, Mineral-rich Environments, and Deposition in South Elysium Planitia, Hellas-Dao Vallis, Isidis Basin, and Xanthe-Hypanis Vallis: Candidate Mars Science Laboratory Landing Sites.

[38] Matthew R., 2012. Geology of Quartz and Hydrated Silica-bearing Deposits near Antoniadi Crater, Mars. Journal of Geophysical Research (accessed at https://agupubs.onlinelibrary.wiley.com/doi/full/10.1029/2011JE004038)

Elementary Divisor

David Torain II

Montgomery College

Abstract

A commutative ring R is called an Elementary Divisor ring if every matrix A with coefficients in R admits diagonal reduction. Rings are commutative with unit and modules are unital. R is an elementary divisor if and only if every finitely presented module over R is a direct sum of cyclic modules.

I

Background

IN ALGEBRA THE ELEMENTARY DIVISORS of a module over a principal ideal domain occur in one form of the structure theorem for finitely generated modules over a principal ideal domain. In ring theory, a commutative ring is a ring in which multiplication operation is commutative. A series of theorems and proofs to this effect follow.

Theorem 1. Let R be a commutative, Noetherian $MP2$ ring with the identity, then R is a direct sum of fields.

Proof: Assume that R is a $MP1$, if not, then there is an ideal that $J \neq Re\,J$ for any idempotent e, since all ideals are finitely generated in a noetherian ring and all finitely generated ideals in a $MP1$ ring are generated by an idempotent. Now, let J be the maximal amount of the set of ideals, which is not of the form Re. Also, let I be the maximal among

$$\{I' | \subset J \text{ and } I' \text{ is of the form } Re\}$$

$$\text{so that } I = Re \text{ and set } f = 1 - e.$$

Then

$$R = I \oplus Rf \text{ and } J = (I \cap J) \oplus (J \cup Rf) = I \oplus (J \cap Rf).$$

Then

$$J \cap Rf \neq 0, \text{ since } I \subset I \oplus (J \cap Rf) \subseteq J.$$

Hence,

$$\exists g \epsilon J \cap Rf \text{ such that } g^2 = g \neq 0 \text{ because } J \text{ is a } MP2.$$

Now

$$I \subset I \oplus Rg = Re + Rg = R(e+g).$$

Moreover, since

$$e = (e+g),$$
$$Re \subset Re(e+g) \subset J.$$

$\therefore \Rightarrow \Leftarrow$. Hence, R is $MP1$ and since R is noetherian and R is the direct sum of fields.

Theorem 2. If R is a $MP1$ and R has ACC, then R is a semisimple Artinian. In particular, if R is commutative, then R is a direct sum of fields.

Proof: Since every ideal is finitely generated and hence generated by an idempotent, each ideal summand of R implies that R has a composition series in the category of R modules. Hence, R has DCC. Thus, since R is semisimple with DCC, R is a direct sum of matrix rings over division rings by Artin-Wedderburn's Theorem. Artin-Wedderburn's Theorem states that an (Artinian) semisimple ring R is isomorphic to a product of finitely many n_i – by–n_i, matrix rings over division rings D_j, for some integers n_j, both of which are uniquely determined up to permutation of the index i. But R commutative implies R is a direct sum of fields.

Theorem 3. Let R be a commutative noetherian $MP2$ ring with an identity. Then the following statements are equivalent:

1. R is a direct sum of fields.
2. For some positive integer k, $M_k(R)$ is $MP2$.
3. For all positive integer k, $M_k(R)$ is $MP2$.

Proof: (3) $\Longrightarrow$ (2) which is trivial. (2) $\Longrightarrow$ (1), since $M_k(R)$ is $MP2$, R is $MP2$. By theorem 1, R is direct sum of fields since it is a commutative noetherian $MP2$ ring with identity. (1) $\Longrightarrow$ (3), if $R \oplus \sum F_i$, then $M_k(R) = \oplus \sum M_k(F_i)$ for all k. The $MP2$ property is preserved by arbitrary direct sums yielding the desired conclusion.

Theorem 4. Let R be a ring with an identity. Then the following statements are equivalent:

1. R is $MP1$.
2. For some positive integer k, $M_k(R)$ is $MP1$.

3. For every positive integer k, $M_k(R)$ is $MP1$.

Proof: (3) $\Longrightarrow$ (2) which is trivial. (2) $\Longrightarrow$ (1), let $A = diag(a_1, \dots, a_k)$, where $a_1 = a_1 = \cdots a_k = a\epsilon R$, which is nonzero. Then $A\epsilon M_k(R)$, since $M_k(R)$ is $MP1$, $\exists$ a matrix $X\epsilon M_k(R)$, X is nonzero, such that $AXA = A$. Then for at least one $x_{ii} \in R$, $(1 \leq i \leq k)$, $ax_{ii}a = a$, where x_{ii} is nonzero and $\therefore$, R is $MP1$. (1) $\Longrightarrow$ (3), is well known since any matrix ring over an $MP1$ ring is $MP1$ due to J. Von Neumann [2]

II

$MP2$ Ring as an Elementary Divisor

Definition 1: For any positive n, let $M_n(R)$ denote a ring of $n \times n$ matrices with entries in R. Where R is called an Elementary Divisor ring, if for every A in $M_n(R)$, there are units P and Q in $M_n(R)$ such that PAQ is a diagonal matrix.

Definition 2: A ring R with identity is called unit $MP2$, if $\forall a \epsilon R$, there is a unit u in $R|uau = u$.

Melvin Henriksen states that if R is a unit $MP1$, then R is an Elementary divisor ring [3]. It is also true that if R is a unit $MP1$, then $M_n(R)$ is a unit $MP1$. Thus, it is natural to investigate if similar properties hold for unit $MP2$ rings and that the unit $MP2$ rings by definition are Elementary Divisor rings. However, I will show that if R is a unit $MP2$, then it is not necessarily true that $M_n(R)$ is a unit $MP2$.

Theorem 5: Let R be a ring with identity and $a \epsilon R$, then the following statements are true:

1. There is a unit u in $R|uau = u$.
2. R is a division ring.

Proof: (1) $\Longrightarrow$ (2), since $uau = u$, then $uau - u = 0$ and $u(au - 1) = 0$. Multiplying everything by u^{-1}, yields u as a right-inverse of a and on the right-hand side yields u as a left-inverse of a. Since R is not necessarily commutative, R is a division ring. (1) $\Longrightarrow$ (2) is trivial.

Theorem 6: By Theorem 9, R is a unit $MP2 \Longrightarrow R$, is a division ring $\Longrightarrow$ is unit $MP1 \Longrightarrow$ by Henriksen's result it follows that R is an Elementary Divisor Ring.

Theorem 7: Let R be a ring with an identity possessing no nontrivial zero divisors and $a \epsilon R$, then the following statements are true:

1. There is a unit u in $R | uau = u$.
2. There is a unit u in R such that au and ua are idempotents.
3. There is a unit u in R such that either au or ua is idempotent.
4. R is a division ring.

Proof: (1) $\Longrightarrow$ (2), if (1) holds, then $(au)^2 = a(uau) = au$ and $(au)^2 = (uau)a = ua$. (2) $\Longrightarrow$ (3), trivial. (2) $\Longrightarrow$ (4), ua is idempotent, then $uaua = ua$; hence, $(uau - u)a = 0$, which implies $uau = u$ since R has no nontrivial zero-divisors; thereby $ua = 1$ and a has a left inverse. Similarly, a has a right inverse and R is a division ring. (4) $\Longrightarrow$ (1), if R is a division ring, then there is a unit y such that $ya = 1$. Then $yay = y$.

Remark: Let D be a division ring. Then surely D is a unit $MP1$ as well as a unit $MP2$. However, $M_n(D)$ is not a unit $MP2$. Thus, R unit $MP2$ does not necessarily imply that $M_n(R)$ is unit $MP2$.

Example. Let R be Q the field of rationales. Then R is unit $MP2$. Now in $M_2(Q)$, let $A = \begin{bmatrix} 1 & 0 \\ 1 & 0 \end{bmatrix}$, then since A is singular, there cannot be a unit or nonsingular matrix B, such that $BAB = B$, for otherwise A would be invertible ,$\therefore \Longrightarrow \Longleftarrow$. Another observation to be made is when an Elementary Divisor Ring R is unit $MP1$, then R is certainly unit $MP1$. For example, any semisimple Artinian matrix ring is unit $MP1$ as demonstrated by Gertrude Ehrlich [3].

References

[1] J. von Neumann. "On Regular Rings", *Proc. Nat Acad. Sci.* U.S.A. **22** 1936, 707-713.

[2] Mevin Henriksen. "On A Class of Regular Rings That Are Elementary Divisor Rings", *Arch. Math. (Basel)*, **24**, 1979, 569-571.

[3] Gertrude Ehrlich, "Unit-Regular Rings", *Portugaliae Mathematica*, **27**, 1969, 209-212.

Bio

Dr. David S. Torain, II is a Full Professor of Mathematics at Montgomery College in Germantown, MD. His research area is in Optimization and Partial Differential Equations, where he studies the use of parametric nonlinear differential equations as a mathematical model.

He was elected as a 2018 – 20019 AAAS Fellow for his contributions to the field of Applied Mathematics, particularly for the discovery of Torain's equations that model the harvesting of species under abnormal conditions.

Delegates to the Washington Academy of Sciences Representing Affiliated Scientific Societies

Acoustical Society of America	Paul Arveson
American/International Association of Dental Research	J. Terrell Hoffeld
American Assoc. of Physics Teachers, Chesapeake Section	Frank R. Haig, S. J.
American Astronomical Society	Sethanne Howard
American Fisheries Society	Lee Benaka
American Institute of Aeronautics and Astronautics	David W. Brandt
American Institute of Mining, Metallurgy & Exploration	E. Lee Bray
American Meteorological Society	Vacant
American Nuclear Society	Charles Martin
American Phytopathological Society	Vacant
American Society for Cybernetics	Stuart Umpleby
American Society for Microbiology	Vacant
American Society of Civil Engineers	Vacant
American Society of Mechanical Engineers	Daniel J. Vavrick
American Society of Plant Physiology	Mark Holland
Anthropological Society of Washington	Vacant
ASM International	Toni Marechaux
Association for Women in Science	Jodi Wesemann
Association for Computing Machinery	Vacant
Association for Science, Technology, and Innovation	F. Douglas Witherspoon
Association of Information Technology Professionals	Vacant
Biological Society of Washington	Vacant
Botanical Society of Washington	Chris Puttock
Capital Area Food Protection Association	Keith Lempel
Chemical Society of Washington	Vacant
District of Columbia Institute of Chemists	Vacant
Eastern Sociological Society	Ronald W. Mandersheid
Electrochemical Society	Vacant
Entomological Society of Washington	Vacant
Geological Society of Washington	Jurate Landwehr
Historical Society of Washington DC	Vacant
Human Factors and Ergonomics Society	Gerald Krueger

(continued on next page)

Delegates to the Washington Academy of Sciences Representing Affiliated Scientific Societies

(continued from previous page)

Institute of Electrical and Electronics Engineers, Washington Section	Richard Hill
Institute of Food Technologies, Washington DC Section	Taylor Wallace
Institute of Industrial Engineers, National Capital Chapter	Neal F. Schmeidler
International Association for Dental Research, American Section	Christopher Fox
International Society for the Systems Sciences	Vacant
International Society of Automation, Baltimore Washington Section	Richard Sommerfield
Instrument Society of America	Hank Hegner
Marine Technology Society	Jake Sobin
Maryland Native Plant Society	Vacant
Mathematical Association of America, Maryland-District of Columbia-Virginia Section	John Hamman
Medical Society of the District of Columbia	Julian Craig
National Capital Area Skeptics	Vacant
National Capital Astronomers	Jay H. Miller
National Geographic Society	Vacant
Optical Society of America, National Capital Section	Jim Heaney
Pest Science Society of America	Vacant
Philosophical Society of Washington	Larry S. Millstein
Society for Experimental Biology and Medicine	Vacant
Society of American Foresters, National Capital Society	Marilyn Buford
Society of American Military Engineers, Washington DC Post	Vacant
Society of Manufacturing Engineers, Washington DC Chapter	Vacant
Society of Mining, Metallurgy, and Exploration, Inc., Washington DC Section	E. Lee Bray
Soil and Water Conservation Society, National Capital Chapter	Erika Larsen
Technology Transfer Society, Washington Area Chapter	Richard Leshuk
Virginia Native Plant Society, Potowmack Chapter	Alan Ford
Washington DC Chapter of the Institute for Operations Research and the Management Sciences (WINFORMS)	Meagan Pitluck-Schmitt
Washington Evolutionary Systems Society	Vacant
Washington History of Science Club	Albert G. Gluckman
Washington Paint Technology Group	Vacant
Washington Society of Engineers	Alvin Reiner
Washington Society for the History of Medicine	Alain Touwaide
Washington Statistical Society	Michael P. Cohen
World Future Society, National Capital Region Chapter	Jim Honig

Washington Academy of Sciences
Room GL117
1200 New York Ave. NW
Washington, DC 20005
Return Postage Guaranteed

5*9*********123****************AUTO**MIXED ADC 207
HARVARD LAW S LIB ERSMCZ
LANGDELL HALL 152
1545 MASSACHUSETTS AVE
CAMBRIDGE, MA 02138-2903